MIT Technology Review

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SEPT/OCT 2014
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WHAT'S YOUR PROBLEM?

We've identified 35 innovators under the age of 35 with bold ideas for solving big problems.

WHERE TO BEGIN READING?

START

Then turn to any page

GENUINELY NEW IDEAS

DUH

What are you interested in?

HOW MUCH MAGAZINES COST

HYPERBOLIC STORIES ABOUT HOW THE SHARING ECONOMY IS "TEACHING US TO LOVE STRANGERS"

MAYBE SOME OF THESE

Then turn to p. 74

ARE YOU CRAZY?

I WAS JUST LOOKING FOR SOMETHING TO READ

I WANT TO BE THE NEXT MARK ZUCKERBERG

I FRET ABOUT LOOMING CATASTROPHE

DO YOU HAVE A PLAN?

Then buy *Wired*

Then come meet people at EmTech, September 23-25

NO

MAYBE A LITTLE

OF COURSE I DO

COULD BE SMARTER

EYE-ROLL

SOMETIMES

Then can you inspire a team?

YES

Well, do you know folks with big ideas?

SOME

LOTS

Where did you study?

WELL, IT WASN'T MIT

Are they smart?

YES

Will you need investors?

Do you have collaborators?

I PREFER TO GO IT ALONE

Do you admire this guy? (p. 62)

Do you admire this woman? (p. 54)

Can you raise venture capital?

Have you made your F-U $?

Do you have a messiah complex?

Do you have a reality-distortion field?

HE SCALED FACEBOOK, BUT QUIP IS JUST AN APP

SURE. I LOVE BRAIN-MACHINE INTERFACES

Do you want to "disrupt" a market?

I DON'T LIKE FOLLOWING DIRECTIONS

Are you a control freak?

THAT'S TOO PALTRY

AREN'T ALL OBSESSIVES?

DUDE, HE'S MY HERO

IMPRESSIVE. BUT BRAIN RESEARCH CAN'T FEED THE WORLD

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HUMANITARIANS


RECENT
Opportunities
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Global Sales Pipeline
Viewing as Michael Foster
Refreshed 8/01/2014 10:37 AM
PIPELINE BY TYPE
Current Month
Add-On-Business
New Business
Replacement
Upgrade
Type
0.00
100.00
200.00
300.00
400.00
Sum of Amount in USD (Thousands)

From the Editor

Seven over 70

Innovation isn't a chauvinist when choosing her servants: older people are as capable of new thinking as the young. Below, in order of age, are seven innovators over the age of 70.

1. Alan Kay, who is 74, is one of the fathers of personal computing: at Xerox PARC, during the 1970s, he was part of the team that developed the networked stations that inspired the first Apple computers. Those workstations were programmed in SmallTalk, a language designed by Kay, which introduced the term "object-oriented computing." Today he is the president of the Viewpoints Research Institute.

2. Ada Yonath, 75, won the 2009 Nobel Prize in chemistry and is to the study of the ribosome what Rosalind Franklin was to DNA. The ribosome is responsible for protein synthesis, but its workings were not understood until recently. Yonath thought that x-ray crystallography could reveal the ribosome's atomic structure, but preparing ribosomal crystals and interpreting the results was thought by many to be impossible. She devised a new technique called cryo biocrystallography and in 1980 created what the Nobel committee called "the first useful crystals" of the ribosome, which led to the publication of the two-part structure of the ribosome in 2000. Today, Yonath is director of the Weizmann Institute's Center for Biomolecular Structure and Assembly.

3. At 78, **Laurence Young** directs bioastronautics in the Harvard-MIT Program in Health Sciences and Technology. In his long career, he has worked on many problems in spaceflight, including flight systems, but his special emphasis has been on the human factors: eye motion, balance, and manual control. He served as an alternate payload specialist for Spacelab on the space shuttle *Columbia*'s October 1993 mission. Today, he is working on safer helmets and wants to build an artificial-gravity machine on the International Space Station.

4. The economist **Robert Solow**, 90, is the creator of the Solow exogenous growth model, currently the dominant theory of macroeconomic growth. Although the mathematics are obscure, capturing shifts in capital, population, and other things, its most important implication is that long-term growth is driven by technological progress. Solow's insight was recognized by the Nobel Memorial Prize in Economic Sciences in 1987. A professor emeritus at MIT, where he has taught since 1949, he still publishes. Recently, he has been wrestling with Thomas Piketty's *Capital in the 21st Century*. (Solow thinks Piketty's analysis of inequality is mostly accurate but his remedies are "hopeless.")

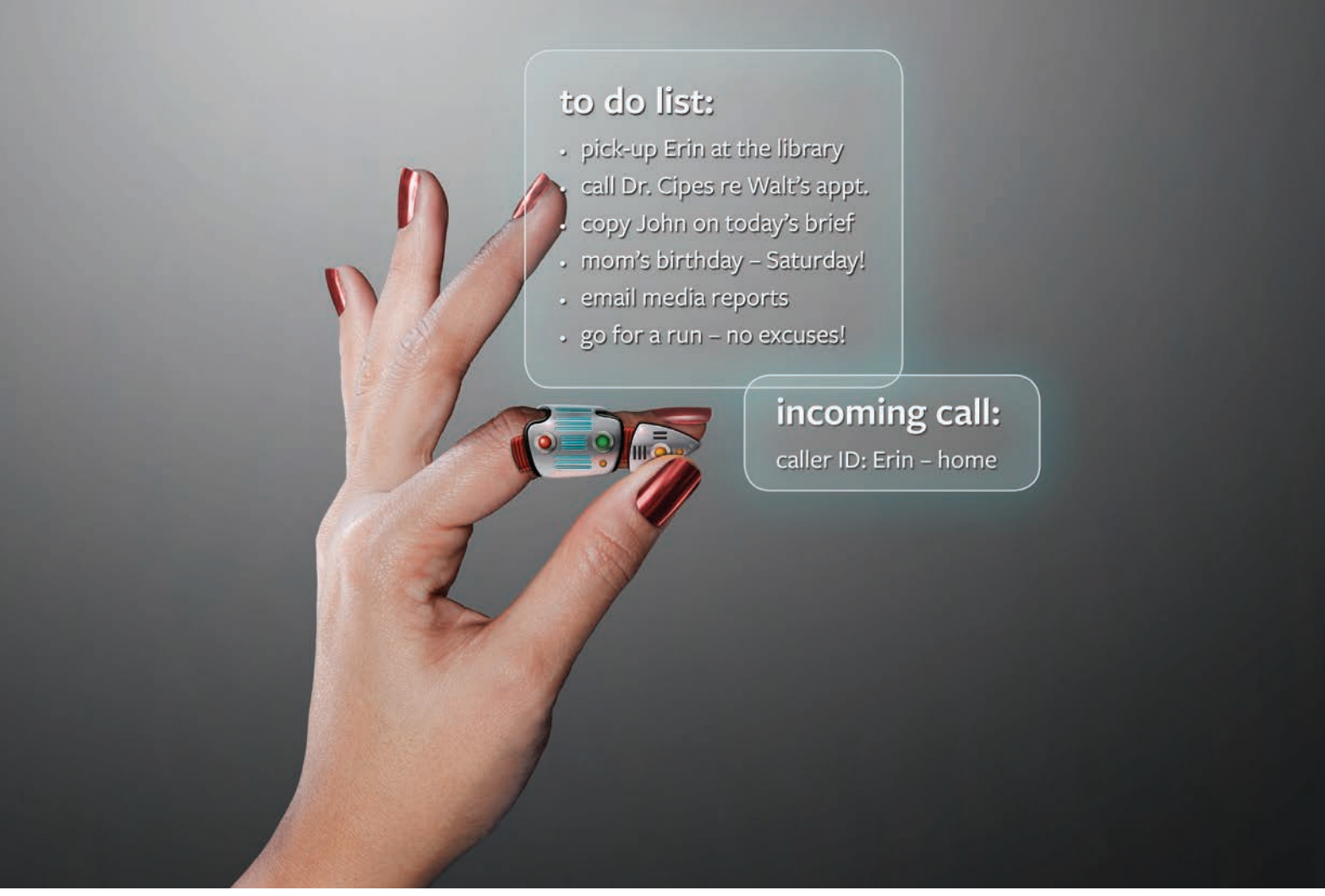
5. Carl Djerassi, 90, contributed to the invention of Norethisterone, the first highly active progestin, a synthetic steroid used in oral contraceptives. Commercialized in the 1960s, the Pill transformed human reproduction and, by making contraception simple and a woman's choice, changed the status of women in societies where it was easily obtained. A professor emeritus at Stanford, since 1989 he has been publishing what he calls "science-in-fiction" (novels where scientists are the protagonists). For the last few years, he has also been writing "science-in-theater," dramas that "smuggle" his interests into literature.

6. Now 92, **John Goodenough** created the cathodes used by rechargeable lithium-ion batteries, but he has other reasons for fame as a mechanical engineer: at Lincoln Labs in the 1950s, he was instrumental in the development of random access memory, and he discovered a number of fundamental rules in magnetism. On retiring from the University of Oxford, he did not retire from innovation: he became a professor at the University of Texas at Austin, where he continues to publish research. In 2012, he identified "a ceramic anode material for a solid oxide fuel cell operating on natural gas."

7. Charles Townes, who invented the laser and shared a 1964 Nobel Prize for his work in quantum electronics, has announced that at the age of 99 it's time to wind down his office at UC Berkeley's physics department. But he insists he will continue to make daily visits to the university's Space Sciences Laboratory.

Finally, a bonus innovator whom age cannot weary: I interviewed **Gene Wolfe** for our *Twelve Tomorrows* science fiction supplement the day after his 83rd birthday. In November, he published a new novel, *The Land Across,* and was working on another. It will be his 31st.

GUIDO VITTI



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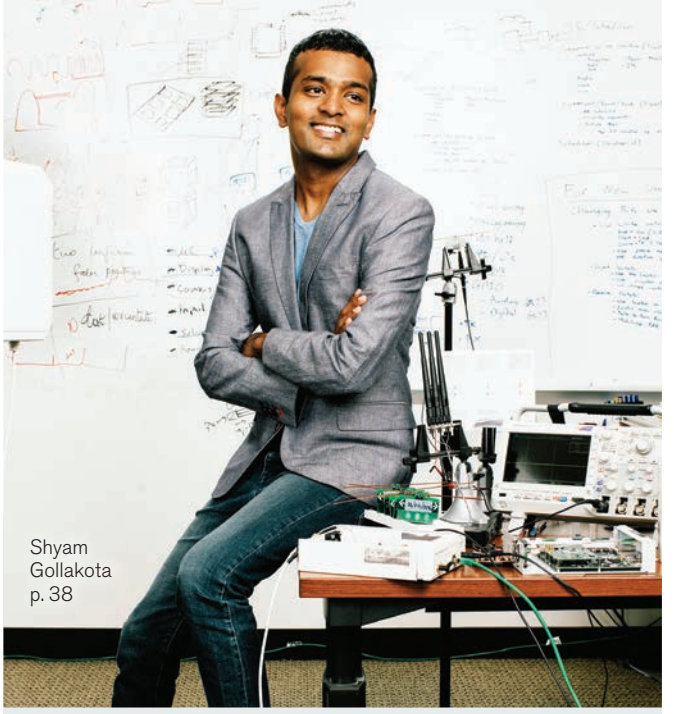

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Innovators Under 35 2014

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BUSINESS REPORT

REVIEWS

DEMO

15 YEARS AGO

"It'd be a mistake for Uber to let public relations trump economics."

Our review of Uber's dynamic pricing begins on p. 74

JOSE MANDOJANA

kia.com/K900

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K900 V8 with VIP Package shown.

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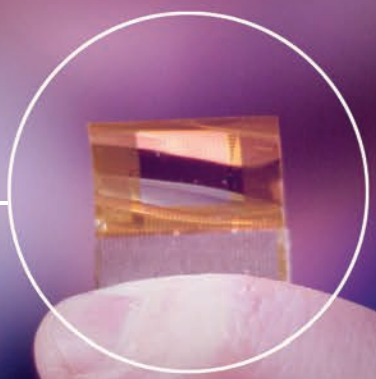
De Technologia non multum scimus. Scimus autem, quid nobis placeat.

We congratulate **Jonathan Viventi, Assistant Professor of Electrical and Computer Engineering,** upon being selected an **Innovator Under 35** by the *MIT Technology Review*.

Jonathan Viventi's research, his dedication to students, and his collaborative spirit are leading us in one of the grand scientific and technical challenges of the 21st century: building an interface between our brains and electronics.



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Five Most Popular Stories

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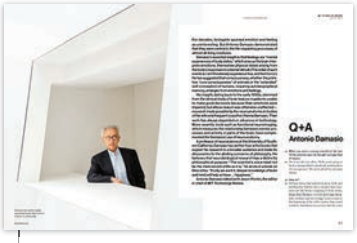
Volume 117, Number 4



1

Cracking the Brain's Codes

No one has yet explained the behavior in animals that we call "instinct." For instance, nest building by birds. It is hard to believe that such complex behavior is stored in the sperm and egg cells of the parent birds. I speculate that there is something much deeper to transfer learning to offspring. **—baruchatta**

@baruchatta: Don't let these God-player wannabes fool you. They are no closer to understanding how the human brain really works than their understanding of animal instinct. **—sochrisjones**

2

Searching for the "Free Will" Neuron

David Talbot writes: "While Kreiman sees no free will, he does believe mechanisms of self-control are built into the circuits that guide him down Broadway and through life." Huh? What the heck are mechanisms of self-control? What self? If no free will exists, Kreiman had no choice but to study in this field, the author had no choice but to write the article, and you had no choice but to read it. My comments are nothing more than predetermined responses to predetermined neural firing from a bunch of other predetermined physical forces. **—littlemas2**

3

The Importance of Feelings

Researchers keep looking for something in the brain that will explain human beings. It will never happen. It's like a mechanic taking apart an engine to find out what's wrong with the driver. One day they'll realize there is more to a human being than some meat and a brain. But while they keep looking at the engine and the rest of the mechanical parts, they will never find the person. Yes, they may be able to find some faulty parts that are damaged or need to be repaired. But they will never find the moral molecule or the honor synapse or the creativity electron. **—Archie**

4

Plan B for Climate Agreements

Your analysis suffers from the same flaw that far too many climate-change commentators trip over—namely, the idea that China or India (or any other country you care to mention) is one entity instead of the millions of individuals at varying stages of development and ambition that it actually consists of. The only way your expectation that China or India is going to start reducing their overall emissions would be for them to tell their citizens to put their dreams and ambitions for themselves and their children on hold. **—jeremymay**

5

Imposing Security

Architects must go to licensed civil engineers to ensure their designs meet building codes. This stifles innovation, but we put up with that because buildings generally do not catch fire on their own, fall down on their own, or poison their occupants on their own. With software engineering, there are well-known techniques for reducing error and risk. However, few people are even aware of the techniques. They mostly come forward in the master's level software engineering curricula. We certainly don't teach them in English or fine arts or wherever else we are finding the bulk of our programmers. **—eburger**

Why Science and Philosophy Can't Be Separated

Your From the Editor column focused on the relationships between neuroscience and philosophy. Scientists and philosophers are interested in different phenomena and use different language, so you wouldn't, on the face of it, expect discoveries in one field to have much impact on the other. But in spite of the differing perspectives of scientists and philosophers, they are confronting the same real world. The situation is similar to that described by Stephen J. Gould, who coined the term "non-overlapping magisteria" in his efforts to reconcile science and religion.

Given that science and philosophy occupy the same world, the separation has to be substantially less than 100 percent. In the past, a de facto insulation has come about as a side effect of each field's developing its own vocabulary and its own dialect of natural language. In the future this will have to change, and there will have to be language for describing human behavior that works equally well in the neurological laboratory and the psychologist's consulting room.

Paul Zeiger
Boulder, Colorado

The Freedom to Say "No"

David Talbot, in "Searching for the 'Free Will' Neuron," offers evidence against "free will." But of course will is not free. We can't will what we don't think about, and the subjects we think about enter our consciousness by entirely unconscious processes. Our brain offers us things to think about, and we can only use our will power on that limited array of topics. It may be, as Patricia Churchland suggests, that the only action by an effort of will is the act of saying "No!"

Rick Norwood
Department of Mathematics and Statistics
East Tennessee State University

Views

Hal Abelson

Dmitry Grishin

Kenneth Oye

COMPUTING

Castles in the Cloud

A Supreme Court ruling acknowledges our digital right to privacy.

ON JUNE 25, THE SUPREME COURT, in *U.S. v. Wurie* and *Riley v. California*, unanimously held that police generally require a warrant to search information on cell phones seized from people who have been arrested. Writing for eight of the justices, Chief Justice John Roberts said the court understood how this ruling might pose issues for police but said, "Our answer to the question of what police must do before searching a cell phone seized incident to an arrest is accordingly simple—get a warrant."

The court was reviewing two cases, one from Massachusetts and one from California, in which arrestees were convicted on evidence obtained from cell-phone data. The U.S. government's argument before the court was straightforward: if you're arrested, the police don't need a warrant to examine the contents of your pockets. The same should hold for the cell phone in your pocket, the argument went, since that kind of search is "materially indistinguishable."

The court rejected that reasoning. As Roberts wrote, saying that searching cell-phone data is indistinguishable from searching physical items is "like saying a ride on horseback is materially indistinguishable from a flight to the moon."

The latest ruling continues an evolution in Fourth Amendment jurisprudence that increasingly decouples legal tests about search and privacy from a focus on physical objects and places, instead taking greater account of information. The court clearly appreciates the range of digital technology and the storage capacity of modern cell phones. As Roberts writes, comparing digital with physical media, "Most people cannot [physically] lug around every piece of mail they've received for the past several months, every book or article they have read," but they can do just that with cell-phone data.

The most encouraging part of the ruling was the demonstration that the court understands something many people do not: the information "on" a cell phone is not necessarily *on* the phone. In Roberts's words: "Cell phone users often may not know whether particular information is stored on the device or in the cloud, and it generally makes little difference."

Our homes may still be our castles, but we don't need to be at home to be protected by the Fourth Amendment. Our castles are increasingly in the clouds. The Supreme Court's ruling is an encouraging demonstration of how to acknowledge the power of information technology without losing sight of first principles.

Hal Abelson is a founding director of the Free Software Foundation and Creative Commons.

ROBOTICS

Affordable Automation

Robots are about to do much more than pick up dust bunnies.

IF YOU HAVE BEEN FOLLOWING TECHnology news, you might be wondering if robots are about to take over our lives. Google in particular has made a slew of robotics acquisitions: the company bought eight robotics companies in the second half of last year, including Boston Dynamics, a maker of legged robots that can balance well enough to climb over obstacles and run, and it recently agreed to buy drone maker Titan Aerospace, whose robotic aircraft could help bring the Internet to remote parts of the world.

What does it all mean? At the least, companies like Google are anticipating business trends. These companies know

SAM KERR

that robotics is important, maybe even revolutionary. But if a revolution is coming to the consumer market, what will it look like? And why would it happen now?

If you're waiting for an invasion of walking, talking, anthropomorphic robots, the coming changes will surprise you. In fact, robots are already an essential part of modern civilization, but they have mainly performed static, repetitive tasks (dispensing cash as ATMs, for example). Now, thanks to trends including the plunging prices of certain technology components, robots will soon be able to tackle an array of more complex, varied tasks with greater degrees of autonomy and intelligence.

The true barrier in this market has been the cost of buying and prototyping the key hardware components that allow machines to gather data and interact with the world around them. And now, for the first time, these components can be tested and produced at a price consumers can afford. We might see a robot that feeds your pet when you're away from home, or a robot consisting of a punching bag with hands that helps you train at boxing.

The Roomba is one of the few success stories in the market for home robotics, and it's a good example of how a task can be automated with the right combination of technology and cheaper components (such as motors and sensors). The market for vacuum cleaners alone is huge: Transparency Market Research estimated it at $11 billion in 2012 and projected an increase to $14.6 billion by 2018, with robotic vacuum sales rising faster than others.

The smartphone and PC revolutions have given us valuable precedents for studying this market. Once we can make useful devices affordable enough, an entire industry of thinkers, engineers, and inventors will spring up to address the rising demand. In fact, we'll probably see an app store for robot hardware as well. Indeed, trying to predict where the robotics industry is headed feels like holding your first iPhone and imagining how it would become part of your life—it's exciting to ponder what the future holds but impossible to know. With the iPhone, Apple created an extraordinary piece of technology. But more important, it produced an *affordable* product. We can now do the same with robots, and the possibilities are endless.

Dmitry Grishin, an Innovator Under 35 in 2013, founded Grishin Robotics, a consumer robotics venture firm.

BIOTECHNOLOGY

Proceed with Caution

A promising technique for synthetic biology is fraught with risks.

GENES IN SEXUALLY REPRODUCING ORGANisms typically have a 50 percent chance of being inherited. Some genes have naturally evolved methods of improving these odds; these are called "gene drives." The genomes of almost every sexually reproducing species contain either active gene drives or remnants of drives. Ten years ago, Austin Burt of Imperial College London proposed designing drives to alter genes in natural populations of mosquitoes. But the difficulty of precisely editing genomes to create engineered drives stymied the realization of Burt's vision. This is about to change.

The recent development of a powerful genome editing tool called CRISPR/Cas9 allows scientists to insert, replace, delete, and regulate genes. Since Cas9 can cut essentially any gene and works in most organisms, it could in principle be used to make gene drives in any sexually reproducing organism. CRISPR gene-drive laboratory experiments in yeast and mosquitoes are under way. Development of purpose-built gene drives in the next few years is very likely.

Unlike most applications of biological engineering, gene drives have the potential to propagate changes throughout populations of organisms with short reproduction cycles. And that creates the potential for powerful positive and negative effects. Gene drives could be used to make it harder for mosquitoes to carry malaria and dengue fever, or they could be used to suppress populations of invasive species such as Asian carp. But they could also be misused—for example, to increase the ability of insects to carry diseases, or to suppress populations of economically significant crops and livestock.

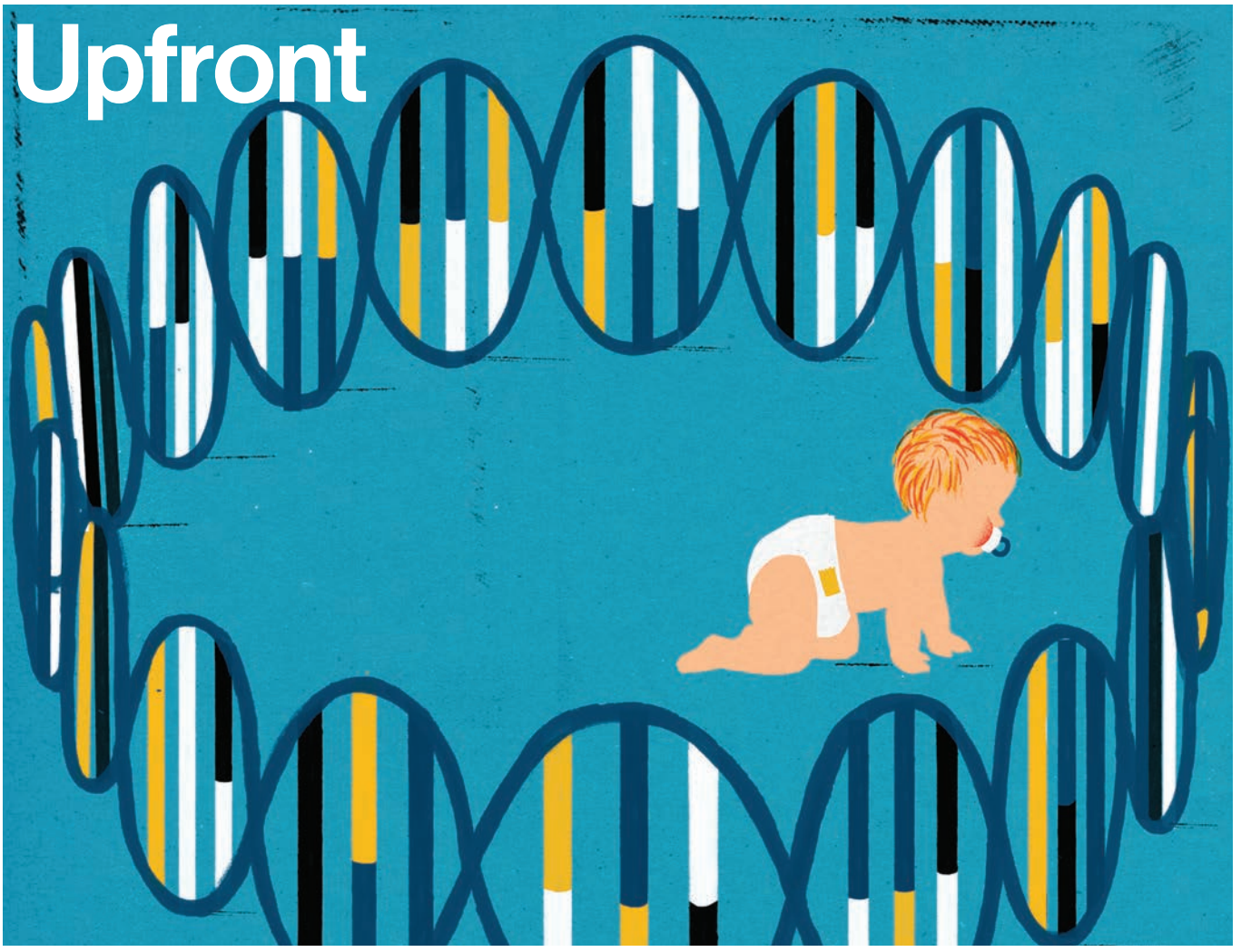
I'm less worried about those kinds of deliberate misuses than I am by the unintended environmental consequences. The truth is that we don't fully understand the interactions between gene drives and the environment, or the mutations possible in drive-bearing organisms.

In July, along with other researchers from MIT, Harvard, and other institutions around the world, I published an article in *Science* that recommends 10 steps biological engineers, environmental scientists, and policy analysts need to take before releasing gene drives. These include research to improve our understanding of drives' properties and side effects, measures to address identified risks, and hedges in case the initial assessments are wrong.

Gene drives don't fit into any existing regulatory frames. There are no environmental regulations that would cover the use of gene drives consistently around the world. So the bottom line is that we need to move cautiously. Scientists need time to evaluate the risks and develop safeguards. Legislators need time to evaluate regulatory arrangements. And the public deserves time for an informed debate.

Kenneth Oye is an associate professor of political science and engineering systems at MIT.

Upfront



For One Baby, Life Begins with Genome Revealed

How a California father made an end run around medicine to decode his son's DNA.

By Antonio Regalado

An infant delivered in California appears to be the first healthy person born in the United States with his entire genetic makeup deciphered in advance. His father, Razib Khan, is a graduate student and professional blogger on genetics who says he worked out a rough draft of his son's genome early this year in a do-it-yourself fashion after managing to obtain a tissue sample from the placenta of the unborn baby during the second trimester.

The idea of sequencing fetal DNA is extremely new and sensitive. Khan, who is finishing a PhD in feline population genetics at the University of California, Davis, had no real medical reason to learn his son's DNA code. He did it to show where technology is headed and because he likes "pushing the envelope."

Khan is already well known in genetics circles as a conservative blogger who publishes provocative views on genetics, race, and reproduction, and he has criticized government regulation of DNA testing. Among his most frequent predictions: sequencing of fetuses will soon become routine, like it or not.

DNA sequencing has become so cheap and easy that its routine use in pregnancy, as a way to get a broad view of a fetus's health, is starting to look inevitable. "In five years we will be offering [genome] sequencing for all routine pregnancies in the first trimester," predicts Art Beaudet,

JUSTIN RENTERIA

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–Thomas Edison

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Upfront

chairman of molecular genetics at Baylor College of Medicine.

What's still not settled is the ethics of prenatal sequencing—or the question of who gets to control the data. In fact, that debate has barely begun. It's such a new idea that the American College of Medical Genetics and Genomics, which sets guidelines for medical geneticists, still has no position on it, says Diana Bianchi, executive director of the Mother Infant Research Institute at Tufts University.

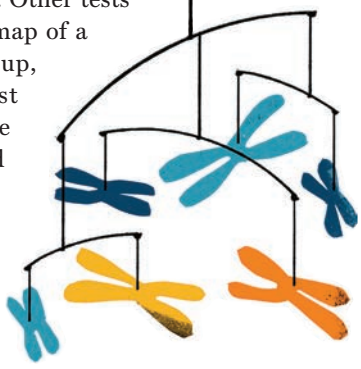
Unlike a targeted test—say, a lab exam for a single condition—genome sequencing reveals every gene. In effect, it provides a test for over 3,000 inherited disorders as well as information about genes associated with higher risks of developing certain disorders. Right now, however, many doctors remain opposed to doing predictive genetic tests on children for diseases that occur only in adulthood.

The ethics of prenatal sequencing have not been settled—nor the question of who controls the data.

Gathering such information on fetuses in utero is even more controversial. A bad mutation could lead parents to an "irrevocable action" such as an abortion, says Bianchi. Yet DNA isn't always destiny—sometimes a person has a genetic defect but no symptoms. All that makes doctors reluctant to delve into a fetus's DNA makeup without good reason.

Several experts contacted by *MIT Technology Review*, including Beaudet and Bianchi, could point to only one published report of a child born with its genome decoded, but that child was ill and didn't live. "My guess is that a few people may have done this privately already," says Jay Shendure, an expert in genomics at the University of Washington. "But this is the only case where someone is being public about it."

The cost of gathering DNA data is plummeting: decoding all six billion letters in a genome now costs only a few thousand dollars. Other tests that provide a coarse map of a person's genetic makeup, called a genotype, cost only $99. So more people are exploring DNA—and for reasons doctors may not always agree with or be able to control. Regulatory tensions have been growing over who gets to interpret gene data. Last year, the U.S. Food and Drug Administration barred the genetics company 23andMe, which is backed by Google, from marketing its $99 direct-to-consumer genotype test, saying it made unproven health claims by telling people what science says about their genes.



Khan had been determined to learn about his child's genome in advance since soon after his wife became pregnant last year. They decided to have a test called CVS, in which tissue was taken from her placenta, which shares the fetus's DNA. Her doctor shipped it off to a lab called Signature Genomics, in Spokane, Washington, for a standard test that looks for missing, duplicate, or broken chromosomes. The test came back normal. But Khan wanted more information, so he asked for the raw data. Signature held onto the sample until Khan eventually got his wife and her doctors to fill out the right paperwork. Then it shipped the baby's DNA to him in California.

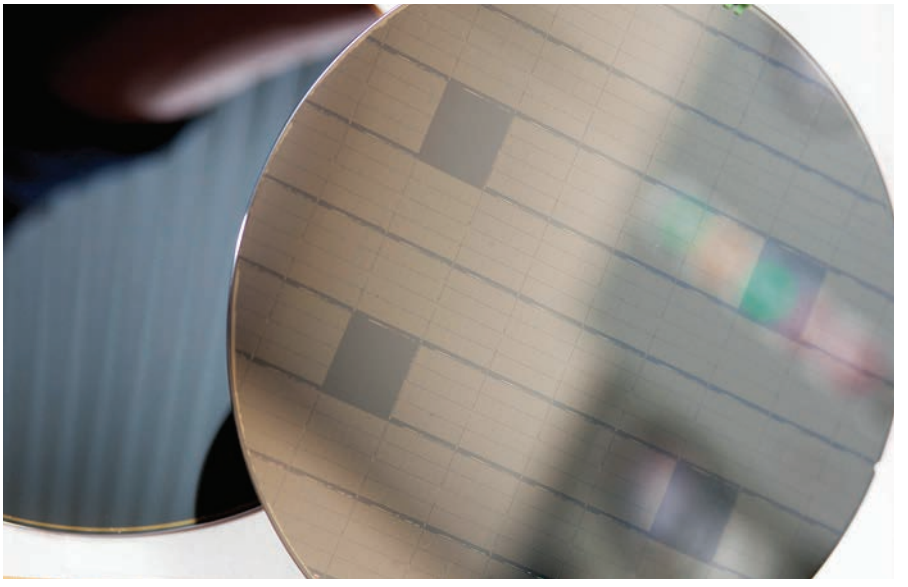
"Once it leaves our building, it's not up to us to decide what the patient does with it," says Britt Ravnan, one of the company's lab's directors and a specialist in chromosome analysis. Ravnan says she is "absolutely sympathetic" to Khan's wish to know more about his son. On the other hand, she cautions, DNA testing in an academic lab could easily generate misleading results. "I worry a little bit that without a lot of experience in interpreting the sequence data on a clinical basis, he might overinterpret or misinterpret things," she says.

When Khan got the DNA earlier this year, he could have ordered simple tests for specific genes he was curious about. But why not get all the data? Khan got a lab mate to place his son's genetic material in a free slot in a high-speed sequencing machine used to study the DNA of various animal species. He then began organizing and interpreting the raw data using free online software called Promethease, which crunches DNA data to build reports—noting genetic variants of interest and their medical meaning. "I popped him through Promethease and got 7,000 results," says Khan.

Promethease is part of an emerging do-it-yourself toolkit for people eager to explore DNA without a prescription. It's not easy to use, but it's become an alternative since the FDA cracked down on 23andMe. To log in, a user has to click on several warnings, including one that cautions not to make reproductive decisions without a doctor.

Exploring his son's genome, Khan found few surprises. He's just a regular kid. "It's mostly pretty boring. So that is good," he says. He makes few apologies for bypassing gatekeepers or for making decisions on behalf of his son, who was born in June: "Our attitude is that you make a lot of decisions for your kids, including ones that may seem sketchy in hindsight."

117 Percentage rise in the value of mobile e-commerce from 2012 to 2013



ANDREW SULLIVAN

Carbon Nanotubes Could Step In to Sustain Moore's Law

Chips made with nanotube transistors, which could be much faster than today's products, should be ready around 2020, says IBM.

By Tom Simonite

For more than a decade, engineers have been fretting that they are running out of tricks for continuing to shrink silicon transistors. Intel's latest chips have transistors with features as small as 14 nanometers, but it is unclear how the industry can keep scaling down further or what might replace silicon.

A project at IBM now aims to have an alternative, carbon nanotube transistors, ready to take over from silicon transistors soon after 2020. "That's where silicon scaling runs out of steam, and there really is nothing else," says Wilfried Haensch, who leads the project. Nanotubes are the only technology that looks capable of keeping the advance of computer power from slowing down, he says, by offering a practical way to make both smaller and faster transistors.

After more than a decade of research, IBM is the first major company to commit to getting the technology ready for commercialization. Haensch's team based the target for commercialization on the timetable of technical improvements the chip industry has mapped out to sustain Moore's Law, a prediction originating in 1965 that the number of transistors that could be crammed into a circuit would double every two years.

IBM recently made chips with 10,000 nanotube transistors (see Demo, March/April 2013). Now it is working on a transistor design that could be built on the silicon wafers used in the industry today, with minimal changes to existing design and manufacturing methods. The chosen design uses six nanotubes lined up in parallel to make a single transistor. Each nanotube is 1.4 nanometers wide, about 30 nanometers long, and roughly eight nanometers from its neighbors. Both ends of the six tubes are embedded into electrodes that supply current, leaving around 10 nanometers of their lengths exposed in the middle. A third electrode runs perpendicularly underneath this portion of the tubes and switches the transistor on and off to represent digital *1*s and *0*s.

The IBM team has tested nanotube transistors with that design, but so far it hasn't found a way to position the nanotubes closely enough together, because existing chip technology can't work at that scale. The favored solution is to chemically label the substrate and nanotubes with compounds that would cause them to self-assemble into position. Those compounds could then be stripped away, leaving the nanotubes arranged correctly.

Last year researchers at Stanford created the first simple computer built using only nanotube transistors. But its components were bulky and slow compared with silicon transistors, says Subhasish Mitra, a professor who worked on the project. IBM hasn't worked out how to make nanotube transistors small enough for mass production, but Mitra says it has devised processes amenable to the semiconductor industry. "We now know that you can build something useful with carbon nanotubes," he says. "The question is, how do you get the performance that you need?"

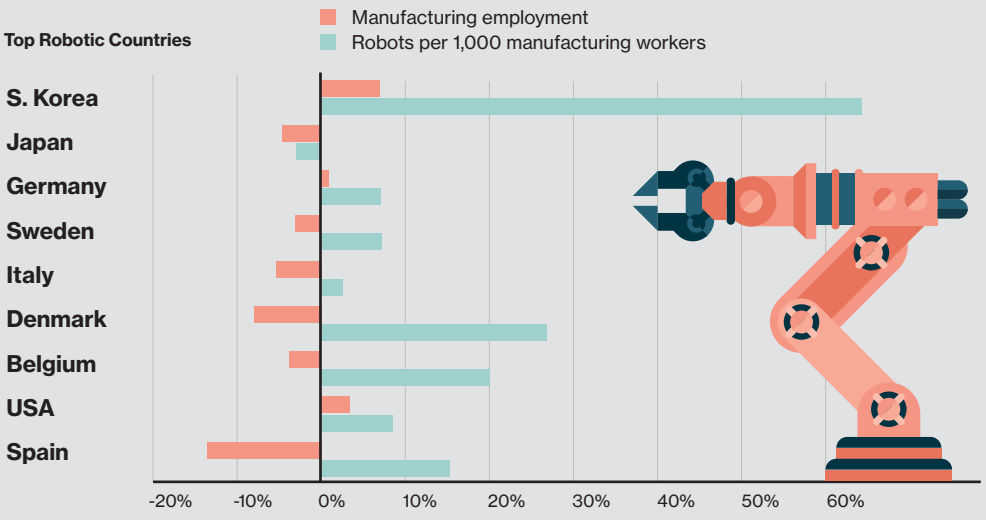
"We now know you can build something useful with carbon nanotubes," says Stanford's Subhasish Mitra.

Upfront

Robots Rising

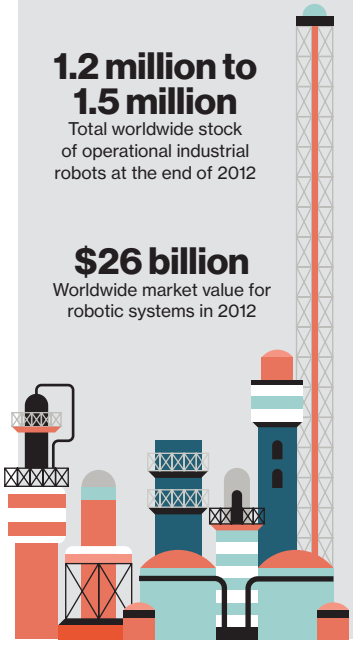
Manufacturers bought more industrial robots in 2013 than ever before. Are these machines mainly putting people out of work? Or are they creating jobs by making certain businesses productive enough to stay in business or launch in the first place? The answer is murky. But in several highly automated countries, the human workforce has declined or grown slowly.

Change in Human Workers and Robots Since 2009

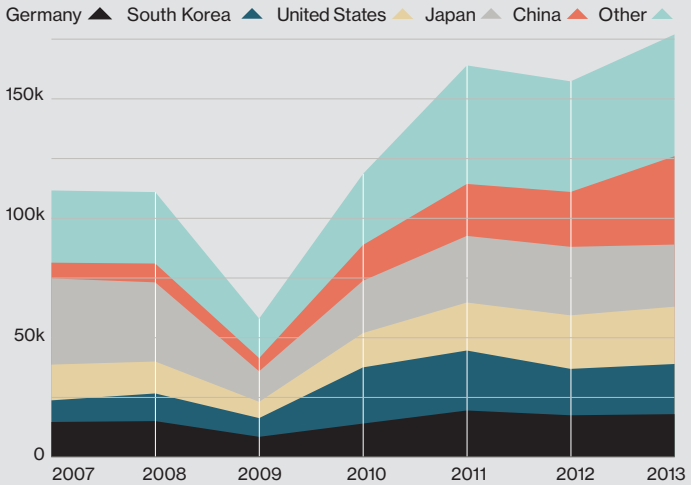


1.2 million to 1.5 million
Total worldwide stock of operational industrial robots at the end of 2012

$26 billion
Worldwide market value for robotic systems in 2012



Sales of Industrial Robots in the Largest Markets



Worldwide Sales of Industrial Robots by Sector

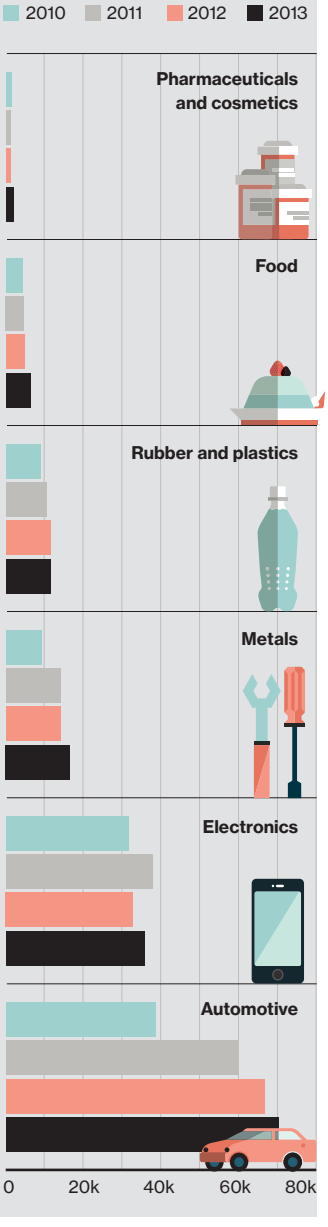


ILLUSTRATION BY LAURA CATTANEO. SOURCES: IFR STATISTICAL DEPARTMENT; WORLD ROBOTICS; U.S. BUREAU OF LABOR STATISTICS. OECD. 2013 ROBOT NUMBERS ARE ESTIMATES. CHANGE IN MANUFACTURING EMPLOYMENT IS FROM 2009 TO 2012, EXCEPT FOR DENMARK AND BELGIUM, WHOSE FIGURES ARE THROUGH 2011

QUOTED

"If you were to visit one virtual planet every second, then our own sun will have died before you'd have seen them all."

—Sean Murray, one of the creators of the computer game No Man's Sky, which has an algorithmically generated virtual universe so vast it might as well be considered infinite.

A Speech Synthesizer Connected Directly to the Brain

Recordings from the brain's surface are giving scientists unprecedented views into how the brain controls speech.

By Courtney Humphries

Could a person who is paralyzed and unable to speak, like physicist Stephen Hawking, use a brain implant to carry on a conversation? That's the goal of an expanding research effort, which over the last five years has proved that recording devices placed under the skull can capture brain activity associated with speaking.

While results are preliminary, Edward Chang, a neurosurgeon at the University of California, San Francisco, says he is working toward building a wireless brain-machine interface that could translate brain signals directly into audible speech using a voice synthesizer. The effort to create a speech prosthetic builds on success at experiments in which paralyzed volunteers have used brain implants to manipulate robotic limbs using their thoughts. That technology works because scientists are able to roughly interpret the firing of neurons inside the brain's motor cortex and map it to arm or leg movements.

Chang is now trying to do the same for speech. It's a trickier task, in part because complex language is unique to humans and the technology can't easily be tested in animals.

The idea is to record brain activity that causes movement of the lips, tongue, and vocal cords.

Chang has been carrying out speech experiments in connection with brain surgeries he performs on patients with epilepsy. He and colleagues use an electrode array to map patterns of electrical activity in an area of the brain called the ventral sensory motor cortex as subjects pronounce sounds like "bah," "dee," and "goo." "There are several brain regions involved in vocalization, but we believe [this one] is important for the learned, voluntary control of speech," Chang says. The idea is to record the electrical activity in the motor cortex that causes speech-related movements of the lips, tongue, and vocal cords. By mathematically analyzing these patterns, Chang says, his team showed that "many key phonetic features" can be detected.

Another study, published this year by Marc Slutzky at Northwestern University, made an attempt to decode signals from the motor cortex as patients read aloud words containing all of the 39 English phonemes (consonant and vowel sounds). The team identified phonemes with an average accuracy of 36 percent. "We expect to achieve much better decoding in the future," he says. Speech recognition software might also help, by guessing which words people are attempting to say.

TO MARKET

Get Up and Go

ReWalk Personal

COMPANY:
Argo Medical Technologies

PRICE:
$69,500

AVAILABILITY:
Now

An exoskeleton designed to help those with spinal injuries walk is now available to buy in the United States, following FDA approval. Made by ReWalk Robotics, based in Yokneam, Israel, the exoskeleton consists of powered leg attachments, a frame that straps to the wearer's body, and a backpack containing a lithium battery, a backup power source, and a computer controller. As soon as the wearer shifts his or her weight forward, the computer activates the knee and hip joints, enabling the person to take a slow, steady step forward with the help of crutches. A wireless controller, worn on the wrist, lets the user switch between different modes for walking, sitting down, and standing up.

COURTESY OF HELLO GAMES (MURRAY); COURTESY OF ARGO MEDICAL TECHNOLOGIES

Upfront

QUOTED

"Our apps were crashing all the time, and they maxed out their data plan in 40 minutes. We now have a whole team of people focused on reducing data consumption."

—Jay Parikh, who heads infrastructure engineering at Facebook, speaking about making smartphone apps for the developing world.

Sharp Shows a Way to Make Ultra-Efficient Solar Cells

New technology could be twice as good at converting sunlight to electricity.

By Kevin Bullis

The best solar cells convert less than one-third of the energy in sunlight into electricity, although for decades researchers have calculated that exotic physics could allow them to convert far more. Now researchers at Sharp have built a prototype that demonstrates one of these ideas. If it can be commercialized, it would double the amount of power a solar cell can generate, offering a way to make solar power far more economical.

Solar cells that exploit a new technique could, in theory, reach efficiencies over 60 percent.

When sunlight strikes a solar cell, it normally produces some very high-energy electrons, but within a few trillionths of a second, those electrons shed most of their energy as heat. The Sharp researchers found a way to extract these electrons before they give up that energy, thereby increasing the voltage output of their prototype.

It's far from a practical device—it's too thin to absorb much sunlight, and for now it works only with a single wavelength of light—but this is the first time that anyone has been able to generate electrical current using these high-energy electrons.

In theory, solar cells that exploit this technique could reach efficiencies over 60 percent. The approach is one of several that could someday make solar power much cheaper than fossil fuels. High-efficiency solar cells would lower the cost of installation, which is often more expensive than the cells themselves.

Exploiting exotic physics requires both understanding the behavior of certain materials and figuring out how to make them with high precision. The Sharp device relies on the ability to make high-quality, nanometers-thick layers of semiconducting materials such as gallium arsenide, which create a shortcut for high-energy electrons to move out of the solar cell.

Another way to achieve ultra-high efficiencies now is by stacking up different kinds of solar cells, but doing so is very expensive. Meanwhile, MIT researchers are studying the transient behavior of electrons in organic materials to find inexpensive ways to make ultra-efficient solar cells. Each of the alternative approaches is at an early stage.

James Dimmock, the senior researcher who developed the new device at Sharp, says he expects his technique will initially be used to help boost the efficiency of conventional devices, rather than to create new ones.

TO MARKET

See the Future

Project Tango Tablet

COMPANY: Google

PRICE: $1,024

AVAILABILITY: 2015

The latest tablet computer from Google will let you shoot videos in 3-D and change your perspective as you play it back. The seven-inch tablet was developed as part of an experimental effort called Project Tango. It features front and rear cameras as well as motion and depth sensors. These extra eyes make it possible to capture a detailed 3-D picture of your surroundings. The "development kit" device is designed primarily for programmers who want to build apps with 3-D functionality. That might include new types of games or novel forms of communication. The device will come with four gigabytes of RAM, 128 gigabytes of storage, and Wi-Fi and LTE antennas. It will run a version of Google's Android operating system.

SUSAN KAUP | MIT TECHNOLOGY REVIEW (PARIKH); COURTESY OF NVIDIA

10 Number of nuclear reactor construction starts in 2013, down from a high of 43 in 1976

Microsoft's Quantum Search for the "Next Transistor"

Investing in quantum physics research could lead to a whole new kind of computer.

By Tom Simonite

Microsoft is making a significant investment in creating the basic component of a quantum computer.

Peter Lee, the company's head of research, likens the effort to research at Bell Labs in the 1940s that produced the silicon transistor, the basis of all computing today. Microsoft had kept its quantum effort relatively quiet, but Lee decided to talk publicly after recent progress. "Early on this was a fringe effort—now the physics community takes us seriously," he says.

Peter Lee speaks at MIT Technology Review's *Digital Summit in San Francisco.*

A quantum computer should be able to complete calculations that are effectively impossible for any conventional machine today. Although the Canadian company D-Wave Systems has sold several machines it says are quantum computers, experts say there is still no definitive proof that they exploit quantum principles and can beat conventional machines.

Microsoft is not attempting to build a complete quantum computer. Rather, its research effort is aimed at developing a reliable version of the qubit, the key building block of quantum information processing. Just like a transistor in a conventional computer, a qubit can switch between states that represent a *1* or *0* of digital data. But a qubit can also exploit quantum effects to reach a "superposition state" that is both *1* and *0*. That would allow a quantum computer to process data many times faster than any conventional computer. Researchers have built qubits of different designs and even used small numbers of them together for very basic calculations. But none are able to maintain a superposition state very reliably. "We believe that current approaches will never scale," Lee says.

Microsoft's research focuses on what's known as a topological qubit, which theory suggests would encode data in a more robust way. Microsoft now has a dedicated quantum computing research lab, known as Station Q, on the campus of University of California, Santa Barbara. It has also been supporting labs around the world with grants, donations, and specialized tools for quantum experiments. Those range from cloud simulation platforms to new types of electronics for use in the supercooled temperatures of quantum hardware experiments.

Meanwhile, Microsoft is already looking ahead to explore what could be done with a system of topological qubits once they are built. "Today we have clear ideas in classical computing about problems we can solve, but it's very hard to conceive what's possible with one of these theoretical machines," says Lee.

SUSAN KAUP | MIT TECHNOLOGY REVIEW (LEE); PHOTO COURTESY OF GUIDO VAN NISPEN | FLICKR (VOGELS)

3 QUESTIONS

Werner Vogels

Amazon's CTO eyes more ways for cloud computing to improve our lives.

How will cloud computing change the way we do things?

This morning in the hotel I stepped on the treadmill, and I wanted it to reconfigure itself automatically to get my music, my newspaper subscription, things like that. I think there's a future where your content just sits in the cloud. Already people can put their music in the cloud, and it will just follow them wherever they are. Once we see more devices becoming connected, we'll see an integration of your content with many more of those.

What do you have to do right if you're going to keep growing?

Security will forever be our number-one priority. It will be forever our number-one investment area. We really want the cloud to be the place where you want to keep your data if you want to have total control over who has access to it.

What security technologies are you experimenting with?

None that we can talk about. But we definitely keep a very close look at all the young businesses that operate in the security arena, because this is a world where I think it's not convenient enough yet for customers. For example, [encryption] key management—customers find that really hard. I'll be happy if in a few years all of our customers encrypt all of their data, or at least all their sensitive business data as well as the personal identifiable data they store. I've been on the warpath for this for quite a while.

—Rachel Metz

Illustration by Matt Chase

Baidu is a fixture of online life in China, but it wants to become a global power. Can one of the world's leading artificial-intelligence researchers help it challenge Silicon Valley's biggest companies?

A Chinese Internet Giant Starts to Dream

BY

Robert D. Hof

WITH ADDITIONAL REPORTING BY CHRISTINA LARSON

PUNK BANDS FROM BLONDIE TO THE RAMONES ONCE played in Broadway Studios, an age-worn 95-year-old neoclassical building surrounded by strip clubs in San Francisco's North Beach. But early on this bright June morning, a different sort of rock star arrives. A small crowd attending a tech startup conference swarms around a tall, soft-spoken man in a blue dress shirt and navy suit who politely poses for photos. Andrew Ng, newly appointed chief scientist at Baidu, China's dominant search company, is here to talk about his plans to advance deep learning, a powerful new approach to artificial intelligence loosely modeled on the way the brain works. It has already made computers vastly better at recognizing speech, translating languages, and identifying images—and Ng's work at Google and Stanford University, where he was a professor of computer science, is behind some of the biggest breakthroughs. After his talk, the audience of about 200 entrepreneurs, venture capitalists, and tech workers sends him off with two rounds of applause.

The avid reception helps explain why Baidu has made Ng, 38, the linchpin of an effort to transform itself into a global force. The company hired him in May to head its research organization, which includes a new artificial-intelligence lab in Silicon Valley and two labs in Beijing, one focused on deep learning and the other on large-scale data analysis.

Often called China's Google, the company plans to invest $300 million in the new lab and a development office on the same floor over the next five years. Ng (it is pronounced "Eng") aims to hire 70 artificial-intelligence researchers and computer systems engineers to work in the new lab by the end of 2015. "It will really target fundamental technology," says Kai Yu, the director of Baidu's Beijing deep-learning lab, a friend of Ng's who urged him to join the company.

Baidu, which hopes to get half its revenue from outside China by 2020, is just one of several large Chinese Internet companies now looking abroad for talent and customers, seeking to make the most populous nation on earth more than just the world's factory. With 632 million citizens online, China claims four of the planet's 10 most-visited Internet properties, up from just one a year ago. The top 20 Chinese Internet companies listed on public exchanges outside mainland China have a combined market value of about $340 billion. The social-networking giant Tencent, whose WeChat mobile messaging service has 100 million registered users from outside China, accounts for almost half of that. And in September, the e-commerce group Alibaba was expected to complete what could be the world's largest initial stock offering ever. Its debut on the New York Stock Exchange could value it at $150 billion.

As they look beyond China, Baidu and other Chinese companies find themselves on a collision course with the established U.S. Internet leaders. It's unlikely that companies such as Google, Facebook, and Amazon will be in danger in Western markets anytime soon. But the field is wide open in much of the rest of the world, where billions of people aren't yet online. Here, companies like Baidu believe they have an advantage because of their experience with customers who are relatively new to the Internet, says Jixun Foo, a

Andrew Ng hopes to lure AI talent to Baidu's new Silicon Valley research lab.

JEFF SINGER

managing partner at the venture capital firm GGV Capital and an early investor in Baidu at a previous firm. "Chinese companies are starting to dream," he says.

Cool Things

THE FIRST THING YOU NOTICE ABOUT Andrew Ng is his voice. Extraordinarily gentle, it is almost a whisper, and his speech carries traces of his birth in London and childhood in Hong Kong and Singapore. As he patiently explains the nuances of deep learning, he sounds as if he's reading a bedtime story to a child. At times, he's scarcely audible above the clack of billiard balls as engineers on a break play pool in Baidu's still largely empty Silicon Valley lab, a 15,000-square-foot office space in Sunnyvale, a few minutes southeast of Google's headquarters. But when Ng turns to his mission at Baidu, his voice rises above the background noise.

Maybe that's because the mission is a grand one: to change the world with artificial intelligence. Ng says he will focus on projects that could "significantly influence" the lives of at least 100 million people. That, he adds pointedly, means more than creating "shiny" apps that rise and fall on the whims of teenage fashion. "Who knows who's going to be the next—boy, I'm even losing track—Snapchat?" he says in a rare flash of snark. "When you build some of the hard technologies that companies like Baidu try to, it gives you a more lasting base to build on."

Baidu is one of many Chinese Web companies on a collision course with Internet leaders such as Google, Facebook, and Amazon as they look abroad for new customers.

Ng's work on artificial intelligence has shaken up a major search company before. He is best known for a project referred to as the Google Brain, which he helped set up inside the secretive Google X research lab in 2011. The project was designed to test the potential of deep learning, which involves feeding data through networks of simulated brain cells to mimic the electrical activity of real neurons in the neocortex, the seat of thought and perception. Such software can learn to identify patterns in images, sounds, and other sensory data. In one now-famous experiment, the researchers built a "brain" with one billion connections among its virtual neurons; it ran on 1,000 computers with 16 processors apiece. By processing 10 million images taken from YouTube videos, it learned to recognize cats, human faces, and other objects without any human help. The result validated deep learning as a practical way to make software that was smarter than anything possible with established approaches to machine learning. It led Google to invest heavily in the technology—quickly moving the Google Brain software into some of its products, hiring experts in the technique, and acquiring startups (see "10 Breakthrough Technologies: Deep Learning," May/June 2013).

Ng, who calls deep learning a "superpower," will build a new generation of such systems at Baidu. Services that may result remain in the brainstorming stage, but he will hint at what they may be. He dreams of a truly intelligent personal digital assistant that puts Apple's Siri to shame, for example. Looking further ahead, the technology could transform robotics, a pet subject for Ng—his engagement photos were taken in a robotics lab—and make autonomous cars and unmanned aerial vehicles much more capable. "We're going to do some cool things here," he says with a grin.

They'll have to if they are to compete: Google, Facebook, Microsoft, and others have been hiring lots of deep-learning experts for their labs, sometimes even from each other. And Baidu still has a lot to prove. Fairly or not, it has the reputation many Chinese companies do for copying the products and business models of U.S. Internet leaders. It's a process cynics dub C2C—"copy to China." Baidu has seemingly tried to emulate Google in countless ways over the years, from its spare search homepage to a head-mounted computer, Baidu Eye, that looks a lot like Google Glass. Baidu has even begun working on self-driving cars. With its new star hire, it appears to be following Google's lead once again.

Ng insists that the C2C stereotype is no longer accurate, particularly for his new employer. "I used to work for the USA's Baidu," he jokes. Then he picks up his phone and says in English, "Please call a taxi for me." A moment later, Baidu's translation app utters the same phrase in Mandarin Chinese and shows the equivalent ideograms on the screen. It's slick—but is it better than Google's translation app, which appears to do the same thing? That's not clear. It's Ng's job to develop cutting-edge technologies that will leave no doubt who is ahead.

Out into the World

BAIDU'S SILICON VALLEY LAB IS LED BY Adam Coates, a 32-year-old who stumbled into artificial intelligence quite by accident. As a Stanford computer science student in 2002, he got talking with Ng, who mentioned that he was working on a project involving remote-controlled helicopters. Coates had built and flown them while at high school in California's Napa

Valley resort town of Calistoga. Ever since, the two have done research together, writing papers on using machine learning for unmanned helicopters, household robots, and image recognition. When Ng left Stanford for Baidu, Coates, then a postdoctoral researcher in Ng's lab, followed. By then, he had begun to see that machine learning would be crucial to just about everything. "It doesn't matter whether you're really excited about language or helicopters," he says. "You can use it to solve any problem."

Ng and Coates have one key quest for their new lab: creating software that can, in a real sense, learn on its own. Until recently, most improvements in areas like speech and image recognition came by training software with data that had been laboriously labeled. For example, teaching software to spot cats would require a database of thousands of images, with any cats identified by humans. You don't have to be an artificial-intelligence expert to see the main drawback of that approach, known as supervised learning. No human child needs to see 50,000 labeled images to recognize a kitty. "We wander around the world and see how things work," Coates says. "The hope is that we can find algorithms that learn the same way." Deep-learning systems might still need to see a lot of cats to spot one on their own, but they can be much more useful because they need minimal human help.

Software smart enough to understand the images, text, and sound in our lives could use that information to make decisions on our behalf—and transform our relationship with technology, says Coates. For instance, it might analyze your vacation photos and recognize the people shown in each one, identifying what they're doing and recognizing landmarks. Then you could find an old shot later by asking for, say, "photos of Mom on the beach." Or you could snap a photo of a shirt with your phone and ask it to find others like that, trusting that instead of just seeing an arrangement of colored pixels, it would apply an understanding of clothing styles, fabric, and your personal taste. Ng envisions our cell phones being able to recognize speech as well as humans can, so you could at last reliably dictate text messages even in a noisy car. He hopes to see e-mail apps that can learn from your interactions with friends and colleagues and then start answering some simple messages on your behalf. Looking further ahead, Ng and Coates may also get a chance to continue their research on robotics, says Yu. "We're not only interested in cyberspace but physical space," he says.

First, however, the Baidu lab in Silicon Valley will try to make it easier to test out deep-learning software, which requires enormous computing power. Training a new speech recognition model can take a week or more, a period Ng would like to cut in half. Last year Coates led a Stanford team to a breakthrough that makes that goal realistic. They built a neural network that roughly matched the Google Brain system for a 50th of the cost—only $20,000—using off-the-shelf graphics chips from Nvidia. That approach could help Baidu get powerful deep-learning infrastructure running at relatively low cost. And it fits well with the company's existing work in Beijing, where simpler clusters of graphics chips have already been used to train deep-learning systems for image and speech recognition.

Software intelligent enough to understand the images, text, and sound in our lives could make decisions for us and take on jobs such as answering simple e-mails.

Air of Mystery

WALKING AROUND BAIDU'S HEADQUARTERS along the technology corridor in Beijing's Haidian district, you might be excused for thinking you had somehow teleported to the fabled Googleplex in Mountain View, California. Free cafeteria? Check. On-site gym? Check. Sleeping pods? Check. Jeans and shorts, T-shirts, flip-flops? Check, check, check. About the only thing breaking the illusion is a giant Baidu bear-paw logo sculpted into the lobby ceiling. It all seems to reinforce the C2C stereotype Ng and others try so hard to quash. And Kai Yu happily boasts that the similarities to U.S. Internet companies are more than skin deep. Like them, Baidu favors flat management, small teams, fast product cycles—and, he adds, his whole face brightening, cool technologies. "Baidu is not so different from a Silicon Valley Internet company," says Yu, who ought to know: he spent six years working at NEC Labs America in Cupertino, two miles from Apple headquarters.

Dig into the history of Baidu, however, and you'll find it has Valley roots of its own. CEO Robin Li cofounded the company in 2000 with biotech salesman Eric Xu, after a stint as an engineer at the Sunnyvale-based search engine Infoseek. Li was armed with a patent for a way to rank sites in search listings by the number of incoming links—filed in 1997, a year before Google cofounders Sergey Brin and Larry Page patented their similar PageRank algorithm. As China's Internet population grew, so did Baidu, enough to attract a $5 million investment in 2004 from Google itself—which later

China's Internet Barons

Known as BAT for their initials, the three leading Chinese Internet companies are beginning to expand overseas.

Baidu

Founded:
2000

Main product:
Internet search. Like Google, Baidu grew large and profitable by selling ads alongside search results and diversified into other areas such as mapping and translation. It now offers search engines for Japan, Brazil, Egypt, and Thailand.

Alibaba

Founded:
1999

Main product:
E-commerce. Alibaba runs several services, including the online person-to-person marketplace Taobao, one of China's most-visited websites. In June, the company opened a U.S. e-commerce site called 11 Main.

Tencent

Founded:
1998

Main product:
Social networking. Tencent's first big hit was the instant-messaging service QQ, now used by 848 million people every month. Its mobile messaging app WeChat is offered both inside and outside China and has almost 400 million active users.

tried to buy Baidu for $1.6 billion in an attempt to head off the Chinese company's IPO, according to *Bloomberg Businessweek*. Instead, Baidu went public in August 2005, and shares rocketed 354 percent the first day. Much as Google had done in the United States, Baidu quickly solidified its hold on China's search market and used the profits to expand into a range of other online services.

Baidu has even beaten back Google, albeit with what some observers believe is an assist from China's government, which blocks access to many Google services inside its borders. And the Chinese company has continued to invest in new ideas, according to early investor Jixun Foo. "Baidu has put a lot of emphasis on the underlying technology, compared with Tencent and Alibaba," he says. That doesn't mean its products are all unique: it offers many Google analogues, including maps, a browser, and cloud storage. Hiring Ng might seem to be another "me too" move. But the company had already invested heavily in deep-learning research and achieved results that rival—perhaps even exceed—Google's.

For instance, the Baidu Translate app has a feature that can, in seconds, identify an object in a photo and name it in written and spoken English. The company's mobile search app can understand what's depicted in a photo snapped on your phone and then find images that are similar. Rather than simply matching colors and patterns, the app knows, for example, whether a photo shows a church or a soccer team. At conferences, Yu likes to demonstrate how that feature beats a comparable one from Google. One slide shows that Baidu found photos similar to one of a dog with a bow on its head. Google returned mostly photos of scantily clad women.

Cherry-picked comparisons aside, the technology has paid rapid dividends for Baidu. In November 2012, only four months after Yu opened his lab in Beijing, the company began using deep-learning technology for voice search. Speech recognition errors fell by a quarter. A similar change helped reduce errors in optical character recognition by almost a third. That made its translation app much better at decoding things like restaurant menus, says Haifeng Wang, Baidu's VP in charge of machine translation.

Yu's neural networks have even boosted Baidu's bottom line. One system learns which qualities of an ad make people click on it more often, selects ads to meet those criteria, and runs them at the most opportune moments. That lets Baidu charge higher prices. Li told investors in April that the technology had helped lift first-quarter profits and revenues.

Still, like Google, even a growing, profitable Baidu faces constant challenges from smaller upstarts and established rivals. Most concerning for the company, its comfortable lead in search has declined in the past year. Baidu's share of searches made in China on desktop computers fell from 80 percent to 75 percent, according to Bloomberg Intelligence. New chal-

lenger So.com, launched in 2012 by the mobile software firm Qihoo 360, now has 16 percent of desktop searches, up from 10 percent a year ago.

The rapid shift of Internet usage to mobile devices, a change that's bedeviled many established U.S. Internet companies, has been particularly dramatic in China, where many people now get their first taste of online life on a smartphone, not a PC. Some 83 percent of people in China now use a mobile device of some kind to get online, and Baidu was caught flat-footed. In the past year, it has moved quickly to reverse the misstep by paying carriers to distribute its mobile apps, spending $1.9 billion to buy the Chinese app distributor 91 Wireless, and redesigning its services and ad formats to work better on phones. All that helped boost the average number of daily users of Baidu's mobile search app to 160 million in the first quarter, up from 130 million six months before. But Baidu must constantly battle native mobile companies and apps to stay relevant.

Breakthroughs from Ng and his researchers might help. The sweeping transition from traditional computers to smartphones and other mobile devices has produced an explosion of sensory data such as images, video, and sound—the kind of data that stumps conventional software but that Ng has shown deep learning can comprehend. His new employer sees an opportunity to leap ahead of its mobile competitors with services that can understand the world.

The same technology might also help Baidu win over many of the planet's five billion people who are not already online and are unaccustomed to the computer technology the developed world has had for 20 years. They will use mobile devices before—likely to the exclusion of—anything else, and deep learning could provide intuitive interfaces that will be attractive to computing beginners. Those newcomers to the Internet—like all of us, really—will not want to learn new modes of interaction, says Ng. They will prefer to speak naturally to their devices to get the information or translation they want.

This type of technology might also help Baidu tailor its search results and apps to different languages and locations. That's something the company has struggled to do, limiting previous efforts to expand outside China. A foray into Japan in 2008 went nowhere because Baidu's search engine failed to cater to local needs. For now, the company has picked a few less-developed regions to focus on: Southeast Asia, the Middle East and North Africa, and Latin America. It launched a search engine for Brazil in mid-July.

"Just as the Industrial Revolution freed a lot of humanity from physical drudgery, I think AI has the potential to free humanity from a lot of the mental drudgery."

For Baidu, becoming more global is also crucial to its ambition to be a leader in technology. Many people outside China, especially in the West, know little or nothing about the company. That Baidu retains an air of mystery among foreigners was apparent at a cocktail party it hosted for the International Conference on Machine Learning, a prestigious annual gathering of artificial-intelligence experts that was held in Beijing for the first time this past June. Jet-lagged researchers from Google, Microsoft, Facebook, and leading universities mingled in the top-floor Happiness Lounge of the 21-story Pangu 7 Star Hotel, taking in dramatic views of the Bird's Nest stadium and Olympic Park. Some said they hadn't heard of Baidu until a couple of years ago and started paying close attention only when Ng joined.

A Baidu employee walks past the "space capsules" where workers can rest at the company's headquarters in Beijing.

That lack of attention from foreigners is part of a larger problem for Baidu. Its inward-looking culture and the Chinese technology industry's reputation for unoriginality limit the company's ability to compete with Google and other U.S. tech leaders, whose workforces are drawn from around the world. Earlier attempts to change that culture have stumbled. Yong Liu, who left Baidu in January after a short stint as its Silicon Valley–based director of open innovation and partnerships, says he was surprised to learn how Chinese-centric the company was. He joined a small Silicon Valley lab that Baidu opened in 2013 and found that all of the 30 or so senior engineers and research scientists there were Chinese. "The purpose of a Silicon Valley R&D lab is to attract the best talent, not just the best

STEFEN CHOW/BLOOMBERG VIA GETTY IMAGES

talent from a minority ethnic group," he says. Baidu's leaders concede the point. "We're making efforts to become a more cosmopolitan company," says Kaiser Kuo, director of international communications. By rebooting the lab Liu joined, hiring Ng and Coates, and expanding its size and scope, they hope to make Baidu's research groups—and eventually the rest of the company—more diverse. For all that executives bristle at comparisons to Google, they are actively trying to act a little more like the icon of Silicon Valley on the global stage.

Culture Shift

BACK AT THE SILICON VALLEY LAB, ANDREW Ng is trying hard to embrace his dual role as cultural catalyst and technical visionary. He used to have no patience with people who talked about what he regarded as the "fluffy stuff" of organizational culture. Now he can't get enough of it. His favorite book lately, to his mild embarrassment, is Eric Ries's *The Lean Startup*, a management handbook for entrepreneurs. He has also turned to serial entrepreneur and startup guru Jerry Kaplan, who says Ng grilled him for advice on hiring engineers and rallying them behind a mission, and held staff meetings to discuss hiring and lab culture. "Now that I'm older, I really appreciate culture and the importance of being thoughtful about it," says Ng.

With his global upbringing, Ng makes a good nucleus for a more diverse research group, says Sebastian Thrun, a Stanford research professor and Google Fellow who started the company's driverless-car project. And Ng is open about the fact that he is a crucial talent magnet for Baidu. He already seems to be attracting a very different kind of person. Among the new hires is Bryan Catanzaro, a graphics chip architect and former Nvidia research scientist—the kind of Berkeley-educated Silicon Valley technologist who otherwise might have joined Google, Facebook, or a hot startup. Ng says he also aims for Baidu Research to be "a little bit porous," sharing ideas with other researchers and the software developer community and becoming as embedded in the Silicon Valley community as its American rivals are. "There's an opportunity to create a culture that's great for research and great for changing the world," he says.

If Ng's plans work out, the world will indeed change in some ways. Baidu will have proved that China's Internet companies can do more than just follow those from the U.S. And perceptive computers will have taken over many tasks we humans must do for ourselves today, perhaps freeing our minds for more creative activities. "Just as the Industrial Revolution freed a lot of humanity from physical drudgery, I think AI has the potential to free humanity from a lot of the mental drudgery," Ng says. It's a Google-worthy goal. But to pull it off, Baidu must chart a path indisputably its own.

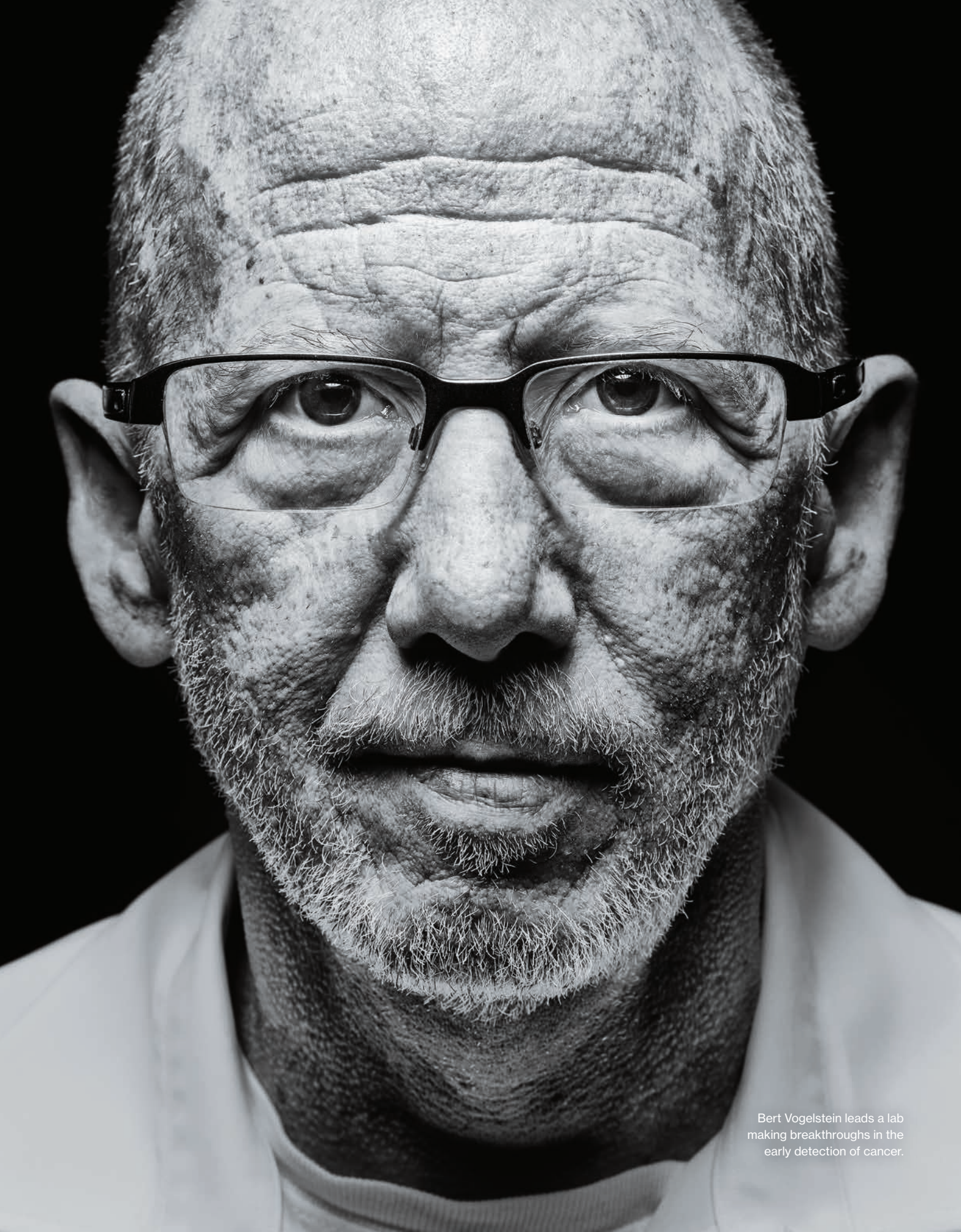
Contributing editor Robert D. Hof wrote about neuromorphic computing in May/June. Christina Larson contributed reporting from Beijing.

Spotting Cancer in a Vial of Blood

He watched his brother die from a cancer that no drug could cure. Now one of the world's most renowned cancer researchers says it's time for Plan B.

By Antonio Regalado

Portraits by Joseph Victor Stefanchik



Bert Vogelstein leads a lab making breakthroughs in the early detection of cancer.

The answers Bert Vogelstein needed and feared were in the blood sample. ¶ Vogelstein is among the most highly cited scientists in the world. He was described, in the 1980s, as having broken into "the cockpit of cancer"

after he and coworkers at Johns Hopkins University showed for the first time exactly how a series of DNA mutations, adding up silently over decades, turn cells cancerous. Damaged DNA, he helped prove, *is* the cause of cancer.

Now imagine you could see these mutations—see cancer itself—in a vial of blood. Nearly every type of cancer sheds DNA into the bloodstream, and Vogelstein's laboratory at Johns Hopkins has developed a technique, called a "liquid biopsy," that can find the telltale genetic material.

The technology is made possible by instruments that speedily sequence DNA in a blood sample so researchers can spot tumor DNA even when it's present in trace amounts. The Hopkins scientists, working alongside doctors who treat patients in Baltimore's largest oncology center, have now studied blood from more than a thousand people. They say liquid biopsies can find cancer long before symptoms of the disease arise.

This particular blood sample, though, was personal. It was from Vogelstein's brother, an orthopedic surgeon one year younger. He was fighting skin cancer, and the disease was already spreading. There was hope he'd respond to a new type of drug, but the treatment causes swelling, and it's difficult to tell from an x-ray or CT scan whether the cancer is melting away or not. So Vogelstein used his lab's new technology. If the cancer DNA had disappeared from the blood, they might celebrate. If it was still there, maybe he could steer his brother to some last-ditch drug.

"We tried to guide the treatment. That was the hope, anyway," says Vogelstein. His voice tightens. He doesn't say what happened next.

The obituary of Barry Vogelstein, born in Baltimore, appeared on July 3, 2013.

We're not winning the war on cancer, and the death of Vogelstein's brother shows why. Too many cancers are caught when they have become incurable. Each year, $91 billion is spent on cancer drugs worldwide, but most of those medicines are given to patients when it's too late. The newest treatments, created at staggering expense, cost $10,000 a month and often extend life by only a few weeks. Pharmaceutical firms develop and test more drugs for late-stage cancer than for any other kind of disease.

"We as the public and as scientists have been entranced by this idea of curing advanced cancers," says Vogelstein. "That is society's Plan A. I don't think that has to be the case." There are other ways to reduce cancer deaths: wearing sunscreen, not smoking, and getting screened to catch cancer early. To Vogelstein, all these preventive steps represent "Plan B" because they receive so much less attention and funding. Yet when prevention works, it has better results than any drug. In the United States, the chance of dying from colorectal cancer is 40 percent lower than it was in 1975, a decrease mostly due to colonoscopy screening. Melanoma skin cancer, too, is treatable with surgery if caught early. "We think Plan B needs to be Plan A," says Vogelstein.

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The new blood tests could make that possible. For the first time, Hopkins researchers say, they are within reach of a general screening tool that could be used to scan broadly—perhaps at an annual physical—for molecular traces of cancer in people with no symptoms. "We think we've solved early detection," says Victor Velculescu, a Hopkins researcher who runs a lab in the building next to Vogelstein's.

Making such screening a routine practice in medicine will be challenging. One difficulty is that while the test may detect the presence of cancer DNA in the body, physicians might not know where the tumor is, how dangerous it is, or even whether it is worth treating. "We have to be cautious about how we talk about that," says Daniel Haber, director of the Massachusetts General Hospital Cancer Center. He believes the DNA blood tests are "far from ready" and says very large studies will be needed to prove that they are useful. "There is a huge bar to get over," he says.

Despite such skepticism, the technology is gaining attention. Tony Dickherber, head of the Innovative Molecular Analysis Technologies Program at the National Cancer Institute, says the idea of scanning blood for tumor DNA was "fringe at best" only three years ago. But now labs and companies from California to London are jumping in, producing a stream of improvements to the blood screening technology and new data supporting it. "People are starting to think that [Vogelstein] is right—this could be the best way to do early diagnosis," he says. "[It] could be done much more widely than other screening technology we have, and you could screen for an incredible range of cancers."

In February, doctors from Hopkins and 23 other institutions provided the largest survey yet of their findings. They studied the tumors of 846 patients with 15 different types of cancer. They found tumor DNA in the blood of more than 80 percent of patients with advanced cancers, the kind that have spread, and about 47 percent of those whose cancer was still localized and at the earliest stage. In advanced colorectal cancer, the DNA was always seen.

The results might not at first appear impressive. A test that misses half the time? The benefit is that the tests are "exquisitely specific," according to Velculescu. If you *do* have tumor DNA, it appears, so far, that you also have cancer. That could give DNA screening the edge over current tests for prostate and breast cancer, which frequently produce false positives. "It's normal to have circulating DNA in the blood; it is not normal to have circulating DNA that matches a tumor," says Stefanie Jeffrey, chief of surgical oncology research at Stanford University.

To Vogelstein, the blood tests mean it may be possible to catch more than half of cancers early on, and potentially cure them with surgery. "If there were a drug that cured half of cancer you'd have a ticker-tape parade in New York City," he says.

Early Days

President Nixon's War on Cancer was launched in 1971, when Vogelstein was in medical school. Years of frustration followed as drugs failed to make much of a dent in cancer deaths. What has changed is that now we know what causes cancer. Vogelstein's work in the 1980s, carried out with colleague Kenneth Kinzler, helped demonstrate the crucial role of mutated genes in the disease. And scientists have now assembled a list of more than 150 genes that appear to be the key drivers. Even though cancer's genetic landscape is complex, all the DNA mutations do one thing: they allow some cells to keep multiplying when normal cells would die. The resulting imbalance is cancer.

For pharmaceutical companies, this insight and the gene list have been the launching point for billion-dollar efforts to develop new drugs for advanced cancers. But to Vogelstein, the knowledge that DNA mutations cause cancer has always also meant something different: that it should be possible to spot the telltale changes early on, well before the disease is usually diagnosed. And in oncology, it's a truism: the sooner you detect cancer, the better your chances.

Consider colorectal cancer, the type Vogelstein has studied most closely. It begins with a single mutation to a gene called *APC*. Yet it takes on average 30 years from that point for the cells to acquire several other DNA mutations they need in order to spread and kill. About 600,000 people die from colorectal cancer each year. "Nearly all of them will die only because their cancer was not detected in the first 27 years of the tumor's existence," Vogelstein says. "That is a huge window to intervene in this process."

The problem has been that until the blood tests, there was no very easy way to look for these mutations. Vogelstein has been working on early-detection schemes since the 1990s, when he began looking for tumor DNA in urine and stool, using the laborious methods available at that time. He believes prevention and screening still receive too little attention, putting him, even now, in an "absolute minority" of researchers. He estimates that 100 times as many research dollars go toward drugs as toward these strategies.

This may explain why, despite his preëminence, Vogelstein seems to have a chip on his shoulder. The Hopkins research group, which includes several other well-known researchers, is quick to publish new ideas, but it often makes the effort to shoot down scientific concepts that are trendy elsewhere. Any young scientist who want to work there, according to the lab's traditions, must first present his or her earlier scientific work while wearing a Burger King crown.

The lab's work on the blood tests has been led by Luis Diaz, an oncologist who has become Vogelstein's protégé. He hit on the

PREVIOUS SPREAD: ISTOCKPHOTO (BLOOD)

idea of testing blood for cancer DNA in 2005, while researching whether a flesh-eating bacterium could be used to eradicate tumors. The work involved transplanting human cancers into mice, and Diaz recalls that he "needed a way to monitor the tumors in the mouse without killing it." He and a colleague decided that they might be able to do that with a blood test. Soon they saw the level of human DNA bouncing down and up as the treatment worked or failed. If they could monitor DNA from a human tumor in mice, wouldn't it work in humans, too?

The idea wasn't entirely new. It's been known since 1948 that free-floating DNA circulates in our veins and arteries. It's normally a waste product of dead cells. But tumors also shed DNA into the blood. The portion of DNA in the blood that comes from tumors can be as high as 87 percent in a person dying from cancer, but often the amount is vanishingly small.

Luis Diaz is using blood tests to declare cancer survivors cured.

When Diaz began looking at the question, all this was not yet fact but muddy possibility. To develop the liquid biopsy, the Hopkins scientists first had to invent ways to pick out the tumor DNA from an overwhelming background of normal DNA. Working with blood donated by patients with colorectal cancer whom Diaz was treating in Baltimore, the researchers initially tracked only four cancer genes. Yet they could see that the tumor DNA in the blood would disappear quickly—even within a day—after these patients had surgery or drug treatments. Healthy control subjects never tested positive. "We realized this test can ask and answer the question 'Do I have cancer?'" says Diaz.

Hopkins believes its test may be more sensitive than any tool doctors have now—at least for cancers that are too small to be seen with an imaging machine. Vogelstein estimates that a tumor has to contain at least 10 million cells, making it about as big as the head of a pin, to shed a detectable amount of DNA. To be visible on an MRI, by contrast, a tumor needs to be about 100 times that size, containing at least one billion cells.

The Hopkins physicians have begun using the DNA tests in an effort to determine whether malignant cells remain behind in patients whose tumors have been surgically removed. Working with Peter Gibbs, an Australian oncologist, they have scanned blood samples from 250 patients who have been operated on for early-stage colon cancer. Most of these people will turn out to be cured, but up to 30 percent are expected to suffer a relapse because not all the tumor cells were removed. The problem is that doctors don't know which patients will relapse. "The surgeon will say, 'Don't worry—we got it all,'" says Diaz. "It's frustrating to me, because then I have to tell the patient, 'We don't really know if you are cured.'" Survivors can get caught in a state of limbo, uncertain whether their disease is coming back, possibly in a more dangerous form. And the situation can drag on for years.

The patients in Australia are checked for tumor DNA in their blood six weeks after surgery. So far, the researchers say, they have correctly identified about half the people who later relapsed. In the future, says Vogelstein, these patients could be flagged to receive chemotherapy, probably saving at least a third of them. Yet the limits of the test are also apparent, since it still missed half the patients whose cancer later reappeared.

Diaz says this may be because whatever cancer cells remain aren't giving off enough DNA to detect. "We may have hit the biological limits," he says. However, the cancer DNA could rise to detectable levels over time, and retesting patients periodically could pick that up. Even though Hopkins's testing remains experimental, Diaz says he has enough confidence in it to tell some patients they are still sick and others that they are probably healed. "Six to eight weeks later, we can tell them if they are cured," he says. "It's very satisfying."

Mass Screening

Vogelstein says his ultimate goal is to turn the blood tests into a way to routinely screen everyone for cancer. The Hopkins researchers believe they have a version of the test that can do that. Instead of tracking a few key cancer genes, they sequence a person's entire genome using DNA from the blood sample. This lets them count how often chunks of genetic material are misplaced or appear scrambled. A large amount of rearranged DNA is a molecular side effect seen only on the chromosomes of cancer cells—a tip-off that cancer is present. But a full genome sequence is still expensive. "If a person has cancer, you don't mind spending $5,000 on a DNA test. But you can't have a test that costs $1,000 that you can do at an annual physical," says

Vogelstein. "The goal is to get the technology cheap enough to use in screening."

That could take time. The cost of DNA sequencing has been falling very rapidly, yet a $100 genome—the price that might be low enough for a general screening test—could be 10 years away. In the meantime, Hopkins has begun several studies, mostly on individuals predisposed to cancer, to determine whether the techniques can catch tumors early in healthy people. One involves 800 people at risk for pancreatic cancer. In these unusual cases, people have cysts on the pancreas that sometimes turn into cancer but sometimes don't. The clinical trial began following patients in 2012, and the researchers will get their first look at the results late this year.

Pancreatic cancer is a good test case for early screening. It's not a very common cancer, but it's the fourth-highest cause of cancer deaths in the United States, because it's cured only 4 percent of the time. (Apple founder Steve Jobs died of it at age 56.) If detected very early, before it spreads, the survival rate rises to about 25 percent.

But extending the DNA tests to everyone is an enormous leap. Haber, the Mass. General oncologist, says the technology, as currently conceived, might tell a doctor if cancer is present. But unlike an imaging scan or a biopsy, it could leave you guessing where in the body it is. Patients would be frightened, doctors uncertain how to act. "The idea of screening healthy people and telling them 'Oh, look, there is cancer somewhere but we don't know where it is'—well, that would be the death of the whole [idea]," Haber says.

Medicine has a precedent of handling predictive tests poorly. Consider the PSA test, which detects a protein linked to prostate cancer. Not only does the test produce false positives a majority of the time, but some of the tumors it actually detects are so slow-growing that they aren't worth treating. Millions of men have ended up getting treated for cancers that ultimately wouldn't have affected them. By one estimate, for every 47 men who had their prostates removed, a single cancer death was avoided. Studies by researchers at Dartmouth College suggest that mammography also leads to overdiagnosis and overtreatment. About 25 percent of breast cancers discovered, and treated, would not have caused any symptoms. "You test everyone and end up treating people for diseases that would never have mattered, either because they wouldn't have progressed or because people die of something else," says Jonathan Skinner, a health economist at Dartmouth. "The downside of early screening can be very high."

At Hopkins, however, Velculescu says he's hopeful that mass DNA screening for cancer will become a reality. "If you can't make a difference, then maybe you would want to remain ignorant," he says. "But I can't imagine that knowing about cancer wouldn't help patients. Maybe we won't dramatically act on every piece of information. Maybe we don't do anything. But with these tests, it would be so easy to keep doing them and say to the patient, 'Let's see how it develops.'"

So far, companies aren't talking loudly about broad screening for cancer in seemingly healthy patients. For now, Personal Genome Diagnostics, a diagnostic testing startup that Diaz and Velculescu founded, and several competitors, like Boreal Genomics and Guardant Health, offer liquid biopsies only to patients who are fighting late-stage cancer. For those patients, the tests might reveal whether a treatment is working in time to try something else if it's not. Another valuable use of the technology is to track the specific DNA mutations driving a patient's tumors. Since many new cancer medications are "targeted"—they block specific molecular processes—patients get them only if their tumor is the kind expected to respond. Doctors can already use DNA tests on chunks of tumor obtained through tissue biopsies. But the noninvasive blood tests could be easier and safer, allowing patients to be evaluated more frequently. Since cancer DNA is constantly mutating, that could help patients switch drugs when appropriate.

To Helmy Eltoukhy, the CEO of Guardant, liquid biopsies are "a huge idea" with many applications. For commercial and medical reasons, his company so far is marketing the tests only to people who have cancer. But he says early screening tests are on his company's road map. "It's obviously the Holy Grail," he says. "Imagine the applications, and that is what we are working on."

I asked both Vogelstein, who is 65, and Velculescu, who is 44, if they had ever tested themselves. Both said no. Yet overall, men in the United States have a 40 percent chance of developing cancer sometime, and the odds rise with age. If these researchers haven't sought the screening, it seems questionable that the broader public will be eager to do it either. For a screening test to be performed widely as a public health measure, the entire medical community will have to participate, and that will take a great deal of time.

Vogelstein isn't naïve. We'll still need new drugs to treat people who develop cancer anyway. But he remains convinced that the best way to beat late-stage cancer is to prevent it from happening. When I offered my condolences to Vogelstein on the death of his brother, he waved them aside. "This is why we do the work," he says. "A hundred years from now, when cancer and death from cancer is a lot less common, a lot of that is going to be due to early detection, not because we can cure a body riddled with tumors."

Antonio Regalado is the senior editor for biomedicine at MIT Technology Review.

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INNOVATORS UNDER 35

All 35 of these people are doing exciting work that could shape their fields for decades. But they're solving problems in remarkably different ways. We consider some of them to be primarily **Inventors**; they're immersed in building new technologies. Others we call **Visionaries**, because they're showing how technologies could be put to new or better uses. **Humanitarians** are using technology to expand opportunities or inform public policy. **Pioneers** are doing fundamental work that will spawn future innovations; such breakthroughs will be taken up by tomorrow's **Entrepreneurs**, people who are building new tech businesses.

Everyone on the list was nominated either by the public or by *MIT Technology Review*'s editors. Some got our attention when they were picked by our international publishing partners as Innovators Under 35 for their regions. After our editors pared the roughly 500 nominees to 80 finalists, outside judges rated the originality and impact, or potential impact, of their work; those scores guided the editors as they crafted the list.

Next Year
Suggest candidates for the 2015 list at **technologyreview.com/nominate**

JUDGES

David Berry
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Edward Boyden
Associate Professor, MIT Media Lab and McGovern Institute

Yet-Ming Chiang
Professor of Materials Science and Engineering, MIT

James Collins
Professor of Biomedical Engineering, Boston University

John Dabiri
Professor of Aeronautics and Bioengineering, Caltech

Jennifer Elisseeff
Professor of Biomedical Engineering, Johns Hopkins

Javier García-Martínez
Director of Molecular Nanotechnology Laboratory, University of Alicante, Spain

Julia Greer
Professor of Materials Science and Mechanics, Caltech

Eric Horvitz
Managing Director, Microsoft Research

Hao Li
Assistant Professor of Computer Science, University of Southern California

Cherry Murray
Dean, School of Engineering and Applied Sciences, Harvard University

Kristala Jones Prather
Associate Professor of Chemical Engineering, MIT

Carmichael Roberts
Entrepreneur and General Partner, North Bridge Venture Partners

John Rogers
Professor of Chemistry and Materials Science Engineering, University of Illinois

Umar Saif
Vice Chancellor, Information Technology University, Punjab

Laura Schewel
Cofounder and CEO, StreetLight Data

Rachel Sheinbein
Managing Director, Balfour Asset Management

Sophie Vandebroek
CTO, Xerox

Ben Zhao
Professor of Computer Science, UC Santa Barbara

INVENTORS

FEATURING:

Shyam Gollakota
Jinha Lee
Fadel Adib
Tak-Sing Wong
Tanuja Ganu
Maria Nunes Pereira
Emily Cole
David He

These people are inventing the devices and technologies that will redefine how we live and work.

Shyam Gollakota

An expert on wireless technology figures out how to power devices without batteries.

PICTURED OPPOSITE

The energy demands of wireless devices have held back the spread of cheap sensors that could be monitoring our homes, the environment, and physical infrastructure such as bridges. Shyam Gollakota has an ingenious solution—a way for these wireless devices to operate without batteries.

Gollakota's prototypes use the fog of radio noise that surrounds us from TV stations, cell towers, and other sources as an energy supply and a means of communicating. By absorbing and reflecting those ambient signals, the devices can send messages to one another and even link to the Internet.

When Gollakota became an assistant professor in the wireless lab at the University of Washington in 2012, he joined a team already working on using ambient radio waves as an energy source. The group had found ways to power simple sensors such as those used for measuring temperature and humidity. But transmitting that data is more challenging. The researchers' devices stored up the trickle of harvested power and occasionally sent out data using a transmitter.

> Even "a primitive computer or device that can only send e-mails" by harvesting radio signals could be valuable.

Gollakota saw that a better solution lay in skipping the conventional, power-hungry transmitter. His battery-free devices—the latest prototype is half the size of a credit card—have antennas that switch between reflecting and absorbing ambient radio signals. In the absorbing mode, they collect enough energy to power chips, sensors, LEDs, and even black-and-white displays. In the reflecting mode, they scatter ambient radio signals in a way that nearby devices can detect. The design makes it possible to deploy battery-free sensors or other devices just about anywhere at low cost, Gollakota says.

His latest prototypes can send and receive signals over 20 meters and between different rooms in a building. They can also connect to the Internet, by communicating up to two meters over Wi-Fi with smartphones or home routers.

Gollakota believes that eventually his energy-scavenging designs will make it possible for ambient radio waves to power stripped-down devices. Many poorer parts of the world lack reliable electricity sources but have strong cellular coverage. Even "a primitive computer or device that can only send e-mails by harvesting these signals," he says, could be valuable.

—Tom Simonite

Jinha Lee

Finding more powerful ways to manipulate and interact with visual data.

"I'm keen to explore better ways to interact with data and environments," says Jinha Lee. "What would be the tools that help us think better? What would be the tools that help us reflect ourselves better?" Statements about his research often come after a pause of 15 to 20 seconds; it is, he says, the time he needs to picture his thoughts in images and translate them into words.

Among the projects Lee worked on as a graduate student at the MIT Media Lab is one he began developing as a research intern at Microsoft Applied Sciences Group; it is a 3-D desktop that allows a user to "reach inside" the screen, flipping through digital documents and windows. He also created a physical pixel that levitates and moves freely about, allowing

COURTESY OF JINHA LEE

Portrait by Jose Mandojana

Gollakota's devices use radio "noise" as a power supply and a way to communicate.

Fadel Adib

Here's how you can use Wi-Fi to track people moving around in other rooms.

"I was born in Tripoli, Lebanon, in 1989. At the time, there was much political violence. The Lebanese civil war ended a year later. Unfortunately, the postwar stability did not last long. When I went to the American University of Beirut, I remember we used to have assassinations or bombings almost every week. When I came to MIT as a PhD student in the Computer Science and Artificial Intelligence Lab, the first thing that shocked me was that I could focus all the time on research.

"In one of our projects, we were just making our Wi-Fi faster by maximizing throughput between nodes. Every once in a while, the system would get messed up, and we would stop getting good results. We realized that there was some person walking in the hallway, and that person's walking was basically changing the channel.

"If I shine a wireless signal at the wall, a huge amount of this signal is going to reflect off the wall. A tiny part of that signal will traverse the wall, reflect off anything that's behind it, and then come back. We realized that we can sense motion using these wireless signals, and that's how we started working on seeing through walls.

"You can track people as they move. You can monitor multiple people's heart rates and breathing. Retail stores that want to understand how people are moving in their stores can track when a person reaches out for a product, looks at it, and puts it back. The police could track if there's a person behind a wall. One of the applications we're thinking of: can you monitor the heart rate of a fetus in the mother's womb without touching the body in any way?

"When I went home to Lebanon and I was talking to my grandmother about it, she was like, 'So, for example, can I put it over here in my living room, and if I fall in the bedroom or in the bathroom, it's going to going to detect my fall and send an SMS to one of my children? Please, make this a product and put it here.'"

—as told to Suzanne Jacobs

Portrait by Webb Chappell

Tanuja Ganu's boxes are a simple way to monitor unreliable power grids.

users to physically manipulate data in three-dimensional space.

Lee, who is from South Korea, cultivated his algorithmic and artistic sense by making origami with his mother, a professional teacher of the art form. These days, as leader of the Interactive Visualization Lab at Samsung Electronics in Suwon, Korea, he is working on user interfaces for the company's next-generation products, including its interactive TVs.

—Yewon Kang

40%
The increase in fuel that's needed when a ship's hull is covered by barnacles

Tak-Sing Wong

Carnivorous plant inspires solution to "sticky" problems.

Tak-Sing Wong has invented one of today's most intriguing and potentially useful new materials. Called SLIPS, for "slippery liquid-infused porous surface," it repels any type of liquid, from oil to water to blood, and prevents organisms like bacteria and barnacles from sticking.

The range of possible applications for the new material is wide: it could be used to coat medical devices such as catheters to decrease the potential for bacterial contamination or cover the hull of a ship to prevent barnacles from adhering to the surface.

Working at the Wyss Institute for Biologically Inspired Engineering at Harvard University, Wong modeled the SLIPS material after the carnivorous pitcher plants *Nepenthes*, which produce a surface that can upend even the oily feet of an ant and send the bug hydroplaning into the stomach of the plant. He assembled micro- and nanoscale structures and filled the empty spaces within the structures with a lubricant that repels both liquids and solids, including ice and bacterial biofilm.

Now an assistant professor of mechanical engineering at Pennsylvania State University, Wong continues to invent novel materials based on nature's inspiration. He hopes to develop wearable devices with camouflage capabilities or gadgets that use a gecko's ability to adhere to walls. "Like Spider-Man, we could walk on walls," he says, "or [use] camouflage like a chameleon that can change color on demand." *—Alexandra Morris*

"Like Spider-Man, we could walk on walls, or [use] camouflage like a chameleon that can change color on demand."

Tanuja Ganu

Simple devices allow consumers to cheaply and easily monitor India's rickety power grid.

Using the small box plugged in between a wall socket and an appliance, Tanuja Ganu can tell you when the electric grid in India is likely to shut down. Sensors inside the device, called nPlug, detect the voltage and frequency of the incoming electricity; analyzing that data over time, the box can determine the periods of maximum power demand on the grid and predict when the need for power will exceed the supply. With that information, the box can schedule when to run water heaters and dishwashers to avert outages, allowing utilities to more easily meet peak demand.

Ganu hopes that the simple data-harvesting gadget and others she is developing will help India's consumers navigate the country's notoriously unreliable power system. Growing up in a small

Maria Nunes Pereira

Patching holes in the hearts of sick infants.

Problem:
Each year, an estimated 40,000 babies in the United States alone are born with congenital heart defects. Some are treated with open-heart surgery, which is invasive and can be risky. Sutures or staples are used to close the holes between the chambers of the heart, but these can damage the fragile tissue. Additional surgery may also be needed as the tissue grows.

Solution:
Maria Nunes Pereira has created a biocompatible glue that a surgeon could use to patch the holes in the hearts of these infants. It can be applied and activated during a minimally invasive procedure. And the adhesive is strong and flexible enough to work in one of the harshest environments in the body—inside a beating heart. Unlike sutures and staples, the glue doesn't harm the tissue when it's applied to the heart, and it doesn't need to be replaced as the child grows.

Pereira developed the glue as a graduate student in the MIT-Portugal program; working with a team of surgeons at Brigham and Women's Hospital in Boston, she demonstrated the adhesive inside a beating pig heart. The procedure required only a single incision. Today, she works at a startup called Gecko Biomedical in Paris, where she is hoping to adapt the technology to human patients within the next two years.

The material could be used in other parts of the body where repairs are invasive or require potentially damaging sutures. "I think these materials have potential to change how surgery is performed and how defects in the body are closed," she says.

—Alexandra Morris

COURTESY OF IBM; COURTESY OF TANUJA GANU; COURTESY OF TAK-SING WONG; SAM KERR

67 million

Americans with high blood pressure

town in India, she studied for exams by candlelight and endured hot days with no fan or air conditioner because the power would shut off for hours with no warning.

She joined IBM Research in Bangalore in 2011 and quickly understood that the basic premise of the so-called smart grid—a two-way connection between consumers and the grid that helps optimize the production and consumption of power—is a nonstarter in her home country. "If you build any solution that requires computation and communications, that's not going to be practical for many developing countries," she says.

Instead, she's designed devices that work autonomously. In tests, nPlug is able to infer the status of the grid using simple pattern-recognizing algorithms and a few weeks' worth of data. For example, voltage dips during spikes in demand, such as morning hours and early evenings. The device can also identify when outages are likely to occur: the frequency of the electric current drops substantially when grid operators can't supply enough power.

If deployed widely, these simple gadgets could help address India's energy deficit without requiring expensive infrastructure investments. "With the amount of data available, there's a lot we can still do with the available power," says Ganu.

—Martin LaMonica

300 million
The number of people in India without access to electricity

Emily Cole

Can we cheaply convert carbon dioxide into something useful?

As the chief science officer of a startup called Liquid Light, Emily Cole is attempting to accomplish something that has long thwarted chemists: finding an economical and practical way to turn carbon dioxide, the chief culprit in greenhouse warming, into useful chemicals.

The idea that could make this possible came from a visit to the Princeton University lab of Andrew Bocarsly. Back in 1994, Bocarsly had published an intriguing but largely ignored paper reporting a way to convert carbon dioxide into methanol without using a lot of energy. Bocarsly couldn't get funding to pursue the research, and the work sat on the shelf until he mentioned it to Cole. She was fascinated and decided to join his lab as a graduate student.

Cole kept tinkering with different catalysts and conditions, increasing the yields of the reactions and learning how to produce other valuable chemicals. The researchers have gone on to show they can convert carbon dioxide into isopropanol, acetone, and more than 30 other chemicals. Moreover, they have shown that light can be used to drive the reactions.

In 2009, Cole and Bocarsly cofounded Liquid Light in Monmouth Junction, New Jersey. The company is working to scale up the conversion process and hopes to market ethylene glycol, a chemical widely used to make plastics, by 2020.

—Stephen S. Hall

David He

This watch could finally get your blood pressure under control.

PICTURED OPPOSITE

David He wants to change how we manage our own health. But at first, he was just trying to find a noninvasive way for hypertension patients to continuously keep tabs on their blood pressure. It was 2009, and He, then a graduate student at MIT, figured people might be helped by a wearable gadget that could record an electrocardiogram—a measure of the heart's electrical activity also known as an ECG.

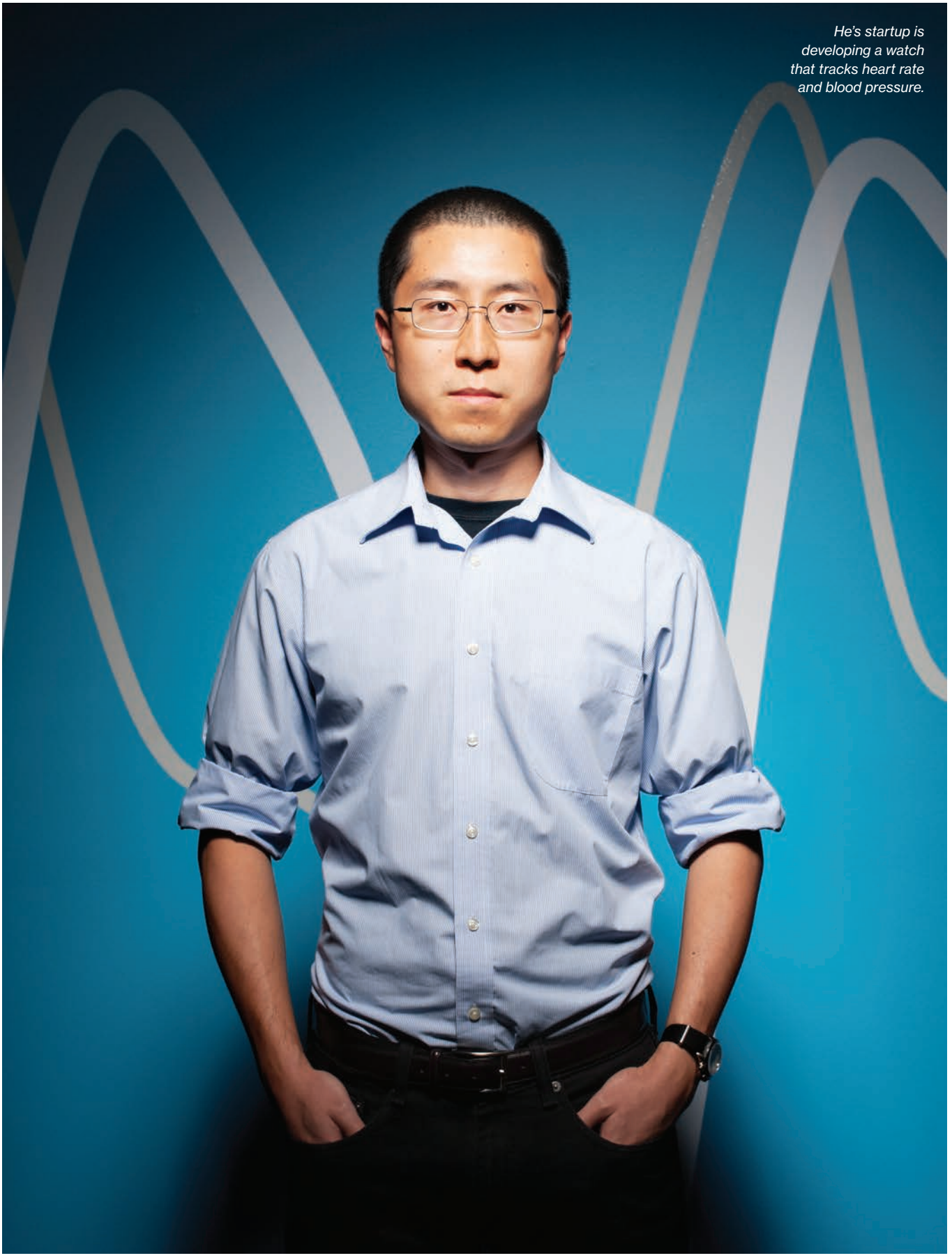
Since the ear is a good place to monitor the body's physiology and pretty easy to hook a device to, He started there: he bought a hearing aid on eBay, removed its guts, and added his own electronics. After doing a lot of jumping jacks and other exercises while wearing the gadget, He looked at the data and saw something odd: a signal that looked similar to an ECG, but with a sharp peak.

There were other weird things, too. The signal was larger than the one from an ECG gathered simultaneously from a heart-rate monitor on his chest, even though the ear was farther away from the heart, and it was noticeably delayed from the chest ECG. As it turned out, what He tracked was actually a ballistocardiogram, or BCG, which is a mechanical signal indicating the tiny body movements that result as the heart pumps blood. First spotted in the 1870s, it gives a more direct view of the heart's mechanical performance than an ECG can, capturing the strength and timing of a person's heartbeats. But it fell out of favor over time, in part because it was difficult to track.

In 2012, He cofounded Quanttus to build a watch-like gadget. There are plenty of wristbands already on the market that track things like steps taken and calories burned, but they don't measure vital signs like heart rate and blood pressure as accurately as Quanttus expects a BCG-based device to do. An optical sensor on the underside of the wristband shines light onto the skin and keeps track of the tissue's selective light absorption, detecting volumetric changes in blood vessels that occur with each heartbeat. This information can be used to deduce heart rate, while an accelerometer measures the body movements that occur as a result of heartbeats.

Though the wristband doesn't yet have a release date, Quanttus has tested it at Massachusetts General Hospital in Boston. The results have been encouraging enough to help the company raise $22 million in venture capital. *—Rachel Metz*

COURTESY OF EMILY COLE
DATA FROM THE WORLD BANK AND THE CENTERS FOR DISEASE CONTROL AND PREVENTION



He's startup is developing a watch that tracks heart rate and blood pressure.

Portrait by Jared Leeds

VISIONARIES

FEATURING:

Severin Hacker
Sarah Kearney
Manu Prakash
Quoc Le
Rumi Chunara
Julie Shah

People who are reimagining how technology might solve perennial human problems.

Severin Hacker

A novel approach to learning languages is making the Web more accessible.

In 2009, Severin Hacker and Luis Von Ahn were holed up in the computer science department at Carnegie Mellon University, turning over a seemingly impossible challenge: how to translate all one trillion pages on the Web, which are mainly in English, for people who speak other languages.

Neither Hacker, a native of Switzerland who was then a PhD student, nor Von Ahn, who was raised in Guatemala and served as Hacker's advisor, was very impressed with the options. Feeding Web pages into Google Translate usually generated gobbledygook, while trying to hire enough translators was impossible. "Translating is a task that people don't want to do," Hacker says. "It is work."

So Hacker made a game out of it. Known as DuoLingo, it teaches foreign languages to anyone with a smartphone or an Internet connection, for free. Unlike most language classes, with their reliance on rote memorization, DuoLingo offers constant interaction. You respond to multiple-choice questions and complete sentences by typing in answers, and you practice phrases by speaking into the microphone. If you answer incorrectly, the app shows you where you went wrong; if you make too many mistakes in a section, you'll have to repeat it. Each course takes around 35 hours to complete and promises intermediate-level proficiency.

But the real genius of DuoLingo is the way it solves the problem that first stumped Hacker and Von Ahn. When you reach the highest levels of a course and translate sentences into the language you're learning, DuoLingo compiles your work with that of other students. That aggregated work tends to produce accurate translations, and media companies such as Buzzfeed and CNN are paying DuoLingo—now spun out as a company, with Hacker as CTO—for foreign translations of their English Web pages.

DuoLingo offers courses in 30 languages and counts 30 million users. Hacker himself recently used it to learn Spanish in order to travel to Guatemala for Von Ahn's wedding. Relying just on the app's lessons, he navigated the airport, hotel, and restaurants, read the newspaper, and got a haircut. "Ten minutes of DuoLingo," he says, "is worth, like, an hour of class." *—Patrick Doyle*

Sarah Kearney

A financial innovator is crafting a way for foundations to invest in clean energy.

PICTURED OPPOSITE

Sarah Kearney wants philanthropists to act more like venture capitalists.

She's created a nonprofit called Prime Coalition to help private foundations invest in energy-related startups. Given that venture funding for clean energy technologies has dropped substantially in the past few years, Kearney's idea could open up a source of much-needed capital from long-term backers.

Radically new energy technologies have proved too risky for most private—and even government—investors. But foundations might not mind those risks, and they need to give away a small portion of their endowments every year if they are to maintain their tax-exempt status. Why not use it to fund companies whose primary goal is fighting climate change?

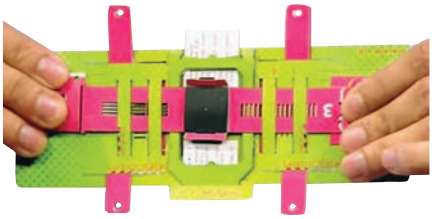
So far, seven foundations have bought into her vision, giving her money to fund Prime Coalition. Next, she hopes to facilitate deals between philanthropists and startups working in renewable energy, energy storage, and related technologies.

Creating the necessary legal and financial structures is a long, complex process. There are potential pitfalls, too. If a startup gets money from a charitable

COURTESY OF DUOLINGO

Portrait by Adam DeTour

Kearney is trying to help energy startups find a new source of long-term backing.



Prakash's Foldoscope is assembled like a paper toy.

67%
Drop in venture funding for clean-energy tech from 2011 to 2013

foundation and private investors, will the foundation's social mission be at odds with the goals of the profit-seeking capitalists? But Kearney says foundations that want to do something about climate change should be involved with technology startups somehow. "Nothing is going to happen at scale unless people are making money," she says. *—Martin LaMonica*

Manu Prakash

Imaginative inventions liberate science from the ivory tower.

Manu Prakash is determined to push down the cost of doing science. Expensive facilities, he says, limit knowledge and expertise to a privileged elite. So from his lab in Stanford's bioengineering department, he's producing instruments that enable people to undertake scientific explorations on the cheap.

Many of Prakash's inventions have a surreal quality. Consider his $5 microfluidic chemistry lab. At a holiday gift exchange, his wife received a hand-cranked music box that used a piano-roll-style punch tape to sound notes. Prakash recognized the mechanism's potential to combine chemical reagents according to a program (the punch tape), without electricity (thanks to the hand crank), at a fraction of the usual cost. He now makes the tiny labs from scratch.

Prakash was raised in northern India and has done fieldwork in Uganda, Ghana, and other developing countries, giving him a view of problems that might not be apparent in most well-equipped academic labs. His insights have led to devices like the Foldoscope, a research-grade microscope made of plastic-impregnated paper, which costs a mere 55 cents, and the OScan, a 3-D-printed smartphone add-on that helps diagnose the oral carcinomas that are responsible for 40 percent of cancer-related deaths in India. His aim, he says, is to put scientific tools in the hands of anyone with a question. *—Ted Greenwald*

Quoc Le

Frustration with waiting for computers to learn things inspired a better approach.

Growing up in rural Vietnam, Quoc Le didn't have electricity at home. But he lived near a library, where he read compulsively about great inventions and dreamed of adding to the list. He decided around age 14 that humanity would be helped most by a machine smart enough to be an inventor in its own right—an idea that remains only a dream. But it set Le on a path toward pioneering an approach to artificial intelligence that could let software understand the world more the way humans do.

That technology sprang from the frustration Le felt at the Australian National University and then as a PhD candidate at Stanford as he learned about the state of machine intelligence. So-called machine learning software often needed a lot of assistance from humans. People had to annotate data—for example, by labeling photos with and without faces—before software could learn from it. Then they

Rumi Chunara

Crucial information about disease outbreaks can be gleaned earlier.

Problem:
Our systems for detecting outbreaks of disease are unreliable. Typically, word of outbreaks bubbles up as patients see health professionals, who report cases to authorities. Those authorities often can't piece the reports together in time to prevent significant numbers of other people from getting sick.

Solution:
Rumi Chunara, a researcher at Harvard Medical School, is mining social media and other online sources for information outside of medical settings.

In one study, Chunara found that a rise in cholera-related Twitter posts in Haiti correlated with an outbreak of the disease. "That's important, because it takes the ministry of health in Haiti a couple of weeks to get their data aggregated," she says. In future outbreaks, tweets could help direct medical workers earlier and ensure that supplies like water purification tablets get where they're needed.

Chunara knows that digital disease detection is not necessarily better. For instance, researchers have spotted inaccuracies in Google's Flu Trends service, which analyzes Web searches and estimates the pervasiveness of the flu. But her goal is not to supplant the traditional chain of command in public health; instead she is augmenting it with new tidbits of information.

To get beyond what might be found from social media, she offered two-cent rewards to people in India who completed a survey about malaria, generating information that could guide deployment of diagnostic and treatment kits. For the United States, she helped develop Flu Near You, a site that creates flu maps based on user-submitted information about symptoms and diagnoses. She's showing that you can get good data even from people who haven't seen doctors. *—Courtney Humphries*

COURTESY OF TED; COURTESY OF MANU PRAKASH; COURTESY OF QUOC LE; SAM KERR
DATA FROM NATIONAL VENTURE CAPITAL ASSOCIATION

"It's so hard to model people—to know exactly what they'll do and when."

had to tell the software what features in the data it should pay attention to, such as the shapes characteristic of noses. That kind of painstaking work didn't appeal to Le. Although personable with other humans, he is uncompromising in his expectations for machines. "I'm a guy without a lot of patience," he says with a laugh.

While at Stanford, Le worked out a strategy that would let software learn things itself. Academics had begun to report promising but very slow results with a method known as deep learning, which uses networks of simulated neurons. Le saw how to speed it up significantly—by building simulated neural networks 100 times larger that could process thousands of times more data. It was an approach practical enough to attract the attention of Google, which hired him to test it under the guidance of the AI researcher Andrew Ng (see "A Chinese Internet Giant Starts to Dream," page 22).

When Ng's results became public in 2012, they sparked a race at Facebook, Microsoft, and other companies to invest in deep-learning research. Without any human guidance, his system had learned how to detect cats, people, and over 3,000 other objects just by ingesting 10 million images from YouTube videos. It proved that machines could learn without labored assistance from humans, and reach new levels of accuracy to boot.

The technique is now used in Google's image search and speech-recognition software. The ultra-intelligent machine Le once imagined remains distant. But seeing his ideas make software smart enough to assist people in their everyday lives feels pretty good. —*Tom Simonite*

Shah uses a glove with lights to train robots to detect human movements.

Julie Shah

This MIT engineering professor is turning robots into ideal colleagues for humans.

"In factories there are usually physical barriers between people and robots. Originally, this was for safety—industrial robots were unwieldy and unyielding. Although robots are increasingly designed to safely share human workspaces, even in these settings, people do one set of jobs and robots do another.

"Imagine if robots could be truly collaborative partners, able to anticipate and adapt to the needs of their human teammates. Such robots could greatly extend productivity. That possibility is really exciting to me.

"Human interaction isn't part of the traditional curriculum for training roboticists. Our field is always pushing to make our systems more autonomous, and have richer capabilities and intelligence, but in that push we tend to look past the fact that these systems are, and always will be, working in human contexts.

"My lab is now focused on how to create robots that make flexible plans and reconsider their best next action based on changing conditions. It's a challenging problem, because it's so hard to model people—to know exactly what they'll do and when. You also have a computational challenge, because the robot needs to reason on all these possible futures so quickly (the way humans naturally do so well). And you need to make the robot interact in a way that a person will accept. But experiments show that when people work with the adaptive robots we have designed, they can complete their task faster, with less idle time, and they even feel safer and more comfortable.

"The interesting thing about this is that there's evidence to suggest the techniques can translate to better human-machine teamwork in almost any setting—from manufacturing to operating rooms to military applications. I think the insights will apply very broadly. After all, good teamwork is good teamwork." —*as told to Will Knight*

Portrait by Christopher Churchill

HUMANITARIANS

FEATURING:

Kurtis Heimerl

Santiago Villegas

George Ban-Weiss

Kuang Chen

By applying technology in novel ways, they are improving lives and expanding opportunities.

Kurtis Heimerl

Inexpensive boxes could help bring mobile coverage to the billion people who lack it.

PICTURED OPPOSITE

Projects intended to help poor, rural communities often founder when innovators lack familiarity with life off the grid. Kurtis Heimerl won't make that mistake. Having spent much of his childhood in the remote mountains of Alaska, he understands the rigors of living without electricity, transportation, and other conveniences. That's one thing that makes his Village Base Station a good bet to bring cellular coverage to regions forsaken by the major carriers.

Heimerl's innovation comes in a gray box roughly the size of a microwave oven. It has solar panels on the outside to power cellular equipment inside, along with the software for management functions like billing and analytics. Secure the box somewhere and link it via satellite to a voice-over-IP network, and you're ready to open shop as a mobile service provider. Heimerl's nascent company, Endaga, sells it for $10,000, promising a return on investment within five years. "In a rural community, your only option is to ask someone like AT&T for coverage, but they just don't care," he says. "So for us to say to local entrepreneurs 'Here, do it yourself' is enormously powerful."

Heimerl's box, with attached antenna, lets anyone offer cellular service.

Heimerl didn't start out as a telecom revolutionary. He enrolled at the University of Washington in 2002 hoping to join the Internet gold rush. However, internships at Amazon and Google soured him on corporate work. Five years later, he went to India for Microsoft Research and became enthralled with bringing communications to underserved areas. When he left Microsoft and joined UC Berkeley's Technology and Infrastructure for Emerging Regions program, he encountered OpenBTS, programming code that bridges Internet telephony and cellular phone networks. "It just popped out at me," says Heimerl, who is still at Berkeley as a postdoc. "We need to take this technology and make it so individuals can operate it."

"It just popped out at me. We need to take this technology and make it so individuals can operate it."

The Village Base Station debuted last year in an Indonesian village that is a four-hour drive over muddy tracks from the nearest city. The community has trouble keeping doctors and teachers, who must journey back to the city just to make a phone call. Heimerl's system brought coverage to 350 subscribers and generated $1,000 per month in revenue for the operator—and it's still going strong.

Just one hitch: it's illegal. Regional mobile providers hold licenses to the necessary airwaves. Indonesian officials were willing to look the other way, but in general, regulation is a significant hurdle for Heimerl's vision of universal access. To resolve that issue, he has helped develop a "white space" workaround that occupies unused radio frequencies until another network needs them. He plans a trial in South Africa this year to demonstrate that it doesn't interfere with other communications. From there, he hopes to expand into any place with an isolated population, an open spectrum, and an entrepreneurial spirit. *—Ted Greenwald*

Photographs by Winni Wintermeyer

Heimerl and colleagues in Endaga's office in Oakland, California.

Santiago Villegas

An online reporting system encourages crime victims and witnesses to speak up.

Five years ago, Santiago Villegas was sitting in his parked car on a street in Medellín, Colombia, when a man came up to him, pulled a gun, and demanded his keys. Villegas handed them over, and the man drove off. Villegas headed to a police station, where it took hours to report the crime. He realized that many people in his position wouldn't have even bothered, given the widespread fear of retaliation.

24%
Portion of crime victims in Colombia who alert authorities

"Martin Luther King said that those who see evil and do not protest support that evil," he says. "But perhaps he did not consider that in a city like Medellín, protest could mean death."

That's when Villegas, a computer scientist, decided to shine more light on crime. He created a system called the Online Safety Project, which lets people report everything from disturbance of the peace to homicide in a matter of seconds, anonymously. Witnesses and other people can add comments or pictures and vote on whether any report is "true" or "not true" and whether it "affects me."

The system got funding from a company that manages security in Medellín and recently expanded to Bogotá. Employees monitor the site around the clock and contact the police when necessary. Every report also gets added to an online map, letting people see which neighborhoods are safest. "This kind of information," Villegas says, "is vital for any person."

—Suzanne Jacobs

George Ban-Weiss

A USC professor who studies climate and pollution influences policy in California.

"Most roofs, historically, have been dark. They absorb sunlight, then transfer heat into the building and into the atmosphere. A very simple solution to that is to design roofs to reflect sunlight rather than absorb it. Cool roofs. Cool roofs could counter somewhere between a half and two degrees Celsius of warming in urban areas.

"In March 2013, an organization called Climate Resolve organized a one-day workshop on cool roofs, with the idea of bringing together researchers and policy makers, including Los Angeles mayor Antonio Villaraigosa. I [had done] a study to take high-resolution aircraft imagery and used that imagery to quantify how much sunlight is reflected versus absorbed. At the workshop I showed a map of Los Angeles with the corresponding reflectivity of each roof in the city. This visual made it clear that roofs cover a large fraction of Los Angeles, and most roofs absorb nearly all heat from the sun. In December 2013 the city council passed a law requiring any new or refurbished roofs on residential buildings to be cool roofs.

"It was extremely fulfilling to know that results from my research contributed to the evidence justifying the first such policy a city has ever passed.

"I try to follow Einstein's suggestion that if you can't explain it to a six-year-old, you don't understand it yourself. I use my own six-year-old as a test bed."

—as told to Adam Popescu

Kuang Chen

A novel way to get data off paper records and into the digital age.

Problem:
Much of the world still relies on paper forms and documents. Getting information off those files into a format that can be searched and analyzed by computers generally requires manual data entry by people, which is costly, slow, and error-prone.

Solution:
Kuang Chen founded a company called Captricity that uses a clever combination of computing and brainpower to read information on paper forms dozens of times faster and more cost-effectively.

Chen developed the technology to capture paper-bound data in countries that had yet to fully harness the power of computing. After false starts in Malawi and Uganda, he put his ideas to the test in Mali in 2011, when he processed nearly 37,000 survey pages detailing perceptions of the government. The job would have taken two clerks an estimated eight months even before they double-checked it. Instead, Chen uploaded snapshots of the forms to Dropbox. Then his software broke up the images into small pieces that were distributed to human readers on Amazon's Mechanical Turk crowdsourcing platform. The Turk transcriptions were used to train machine learning algorithms that progressively took over the work; ultimately, human readers were used only to interpret the most ambiguous entries. The process took a week.

The same approach that works in African villages can be useful in any organization that still relies heavily on paper forms. Captricity funds its free or low-cost services in poor countries in part with revenue from paying customers such as Dell, Harvard Law School, and the U.S. government. *—Ted Greenwald*

COURTESY OF SANTIAGO VILLEGAS. COURTESY OF GEORGE BAN-WEISS. SAM KERR
DATA FROM COLOMBIA'S NATIONAL ADMINISTRATIVE DEPARTMENT OF STATISTICS

Feng Zhang

Investigator,
McGovern Institute
for Brain Research
at MIT

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Broad Institute

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The frontiers of science provide ample space to explore innovation. Meet nine of the pioneers.

Duygu Kuzum

Brain-inspired chips could mean better computer processing and neural implants.

Inspired by the architecture of the brain, Duygu Kuzum has designed electronic devices that mimic the behavior of synapses, the connections between neurons. When she was a graduate student at Stanford, Kuzum initially focused on high-performance electronics for computer processors. But during a summer internship at Intel, she had a kind of neuro-epiphany. "I was always thinking, 'Okay, now I'm designing and trying to increase the performance of these electronic components and trying to build a computer to be used by another computer, which is the human brain,'" she says. "And I realized that these two computers are built on and operate on fundamentally different principles."

So Kuzum set out to design a computer chip based on the way the brain's synapses process information. Unlike computer circuits, which are based on the binary choices of on or off, *0* or *1*, synapses can operate more like a dimmer switch, with variations in strength. Using that insight, Kuzum and her Stanford colleagues created "nanoelectric synaptic grids"—miniaturized computer circuits that can understand and recall rather sophisticated patterns. The prototype opens the way to the development of small, portable, energy-efficient computers that can process complex sources of data, such as visual and auditory information. That same architecture, Kuzum believes, can also be used to design neural implants and prosthetic devices that act as supple, realistic interfaces between computer controls and living brain tissue.

$109 billion
The annual cost of heart disease in the United States

Kuzum, who grew up and went to university in Ankara, Turkey, moved to a postdoc position at the University of Pennsylvania in 2011 and is now trying to create a new type of brain electrode using graphene, a form of carbon that is both flexible and transparent. Implanted in neural tissue, the electrodes could let researchers record the activity of nerve cells while simultaneously imaging their behavior.

> "We cannot 100 percent replicate the brain, [but maybe we can] build a system that's more brain-inspired."

"We cannot 100 percent replicate the brain," Kuzum concedes. But, she suggests, maybe we can "build a system that's more brain-inspired." *—Stephen S. Hall*

Megan McCain

Heart on a chip paves the way for personalized cardiac medicines.

PICTURED OPPOSITE

What if there were a way to use a patient's own cells to test his or her response to a cardiac drug before it was administered? Megan McCain, an assistant professor at the University of Southern California, is developing a so-called heart on a chip, roughly the size of a quarter, to do just that.

When she was a postdoc at Harvard, McCain began collaborating with cardiologists at Boston Children's Hospital. Her colleagues took skin cells from a patient, reprogrammed them to become stem cells, and turned the stem cells into heart cells. "Those heart cells should work pretty much the way your native heart cells should work," she says. "They'll have the same genetic information." McCain then engineered tissues from these heart cells and used the heart-on-a-chip system to examine how the structure and function of healthy tissues differed from that of diseased tis-

COURTESY OF DUYGU KUZUM
DATA FROM CENTERS FOR DISEASE CONTROL AND PREVENTION

Portrait by Misha Gravenor

McCain hopes her device will provide a more accurate way to test heart drugs.

Maryam Shanechi

Using control theory to build better interfaces to the brain.

"I was born in Iran. My family immigrated to Canada when I was 16. My parents wanted a better education for me, my brother, and sister. I started out working on information theory, coding theory, and wireless communication. But I wanted to more directly impact people in my research. When I was looking for a PhD topic, I came across neuroscience, and I realized that the same principle could be used to treat brain disorders.

"So I moved from decoding wireless signals to decoding brain signals. I develop brain-machine interfaces that record the activity of neurons while someone plans a movement. This could one day allow disabled patients to move just by thinking about it.

"My work takes a lot of insight from control theory. Say you reach for a glass of water—your brain wants that to happen in a certain time frame, and it's getting visual feedback, and you can adjust the speed. The brain acts as a 'feedback controller,' and I have built models for how that works. I also work on brain-machine interfaces for anesthesia. We decode the level of brain activity and adjust the anesthetic accordingly.

"I started as a professor at Cornell University and moved to the University of Southern California in July. As part of the Obama BRAIN initiative, I'm involved in a project to revolutionize treatments for neuropsychiatric disorders, such as PTSD and depression. We will create a brain-machine interface to decode the neuropsychiatric state of the brain, and decide on a set of electrical stimulation patterns to alleviate the symptoms in real time. This would be an automatic controller—a closed-loop system. And I will build that.

"We know nothing about the signatures of neuropsychiatric disorders in the brain. We need to discover those. I am really excited, because there is so much we don't know."

—as told to Antonio Regalado

Portrait by David Lauridsen

Viventi's brain interface has both an array of sensors and flexible electronics.

> "It is very mechanical, and it has an electrical side. I appreciate how delicate, complex, and interesting the heart is."

sues. The patient-specific cells living on a chip offer a more accurate way to predict how an individual's heart will respond to a drug than, say, tests using lab animals.

McCain and her team have used the technology to test drug treatment for Barth syndrome, a rare cardiac disease caused by a single-gene mutation. She hopes that this chip will someday be used to test treatments for genetically caused cardiac diseases in general.

Other researchers have also created simulated organs on chips, but the heart presents specific challenges. "It is very mechanical, and it has an electrical side," says McCain. "I appreciate how delicate, complex, and interesting the heart is."

—Alexandra Morris

Guihua Yu

Electronic gels could lead to sensors and batteries that are more like biological tissue.

Since starting his lab at the University of Texas at Austin in 2012, materials scientist Guihua Yu has been controlling the three-dimensional nanostructure of materials to make electrically conductive gels that can serve as electronic skin, more efficient battery electrodes, or tunable chemical sensors.

Hydrogels, which are flexible, squishy networks of polymers, are great for supporting the growth of cells in research experiments or binding together active ingredients for drug delivery. But they typically are lousy at conducting electricity. In contrast, electrically conductive polymers are valuable in electronics—for example, in new types of plastic solar cells—but typically can only be made into thin films. Yu figured out how to link conductive-polymer building blocks to make nanostructured gels that had the best qualities of both materials.

One gel can be used to hold glucose-binding enzymes and nanoparticle catalysts, key elements of a rapid, highly sensitive glucose sensor that might be used for diabetes management. Another makes for a more resilient battery electrode with higher energy density.

—Katherine Bourzac

Kay Tye

Identifying how the connections between regions of the brain contribute to anxiety.

Neuroscience has often focused on dividing the brain into regions, pinpointing which individual neurons are responsible for specific functions. Kay Tye's vision of the brain is defined less by discrete addresses than by the roads between them—the connections between groups of neurons. "I think neuroscience as a field is at this threshold of a new understanding of the brain in terms of circuits," says Tye, a principal investigator at the Picower Institute for Learning and Memory at MIT. The connections a cell makes could be at least as important as its location, she believes.

As a postdoc at Stanford University, Tye took advantage of a relatively new technology called optogenetics, which allows researchers to use light to turn specific, genetically modified neurons on and off in lab animals.

Manipulating the connections in mice between a group of neurons in the amygdala with a group in the hippocampus, she precisely altered behaviors related to both anxiety and social interaction to tease apart the specific connections she suspected played a critical role in anxiety. When the circuit is inhibited, a mouse that normally avoids open areas explores them freely, and when it's activated, the mouse runs for cover. In a subsequent study, Tye showed that inhibiting a circuit made a mouse sniff and nudge a strange mouse in its cage, while activating it made the mouse ignore the stranger—a test of the animal's tendency toward social interaction.

The idea that manipulating connections between small bundles of brain cells could instantly reshape behavior opens up new possibilities for treating brain disorders. Current drugs, she says, "target the entire body and bathe the whole brain in this soup," creating many unwanted side effects. If scientists can find a way to safely manipulate the human neural connections involved in feelings such as anxiety, therapies might be more precise and cause fewer side effects.

First, researchers will have to identify the various connections that can be manipulated this way. It's an enormous task given the complexity of the brain. But at least Tye's breakthroughs have helped get them on the right road.

—Courtney Humphries

86 billion
The number of neurons in the brain of an adult

Jonathan Viventi

A high-resolution interface reveals the brain storms of people suffering seizures.

On his cell phone, Jonathan Viventi, a biomedical engineer at New York University's Polytechnic School of Engineering, displays what looks like a meteorologist's map of a fast-moving storm: red, orange, yellow, green, and blue patches swirl in ominous, complex patterns. In fact, the video represents the highest-resolution electrical data yet recorded over a large surface of an animal's brain during an epileptic seizure.

Previously, researchers using lower-resolution technology had observed repetitive spik-

COURTESY OF GUIHUA YU; COURTESY OF NAJAT KESSLER; COURTESY OF NYU

ing patterns during seizures. But those recordings were "vastly undersampling the electrical activity of the brain," says Viventi. His innovation was to develop a better interface that could capture more detail, revealing patterns of waves rotating, changing direction, and moving across the brain's surface.

The improved imaging is possible because of an implant that is roughly one centimeter square and can be positioned, in theory, anywhere on the surface of the brain. The implant incorporates flexible electronics into an array of sensors; indeed, Viventi was the first to move electronics, which are usually rigid and located far from such sensors, directly to the brain's surface. "This allows us to amplify and combine signals directly at the source, so that we don't need to have one wire for each sensor," he says. That, he adds, "lets us build much higher-resolution interfaces with the brain."

Viventi imagines that doctors will use his implants as a temporary way to monitor seizures and plan treatment, including further surgery, in people with epilepsy. In the longer term, he hopes that permanent implants for patients with severe epilepsy can sense brain activity and stimulate the appropriate regions. He hopes to win approval for clinical trials of his devices, though to date the team has only done experiments on animals.

50 million
The number of people with epilepsy worldwide

Viventi first became interested in epilepsy when he was a graduate student in bioengineering at the University of Pennsylvania. It was because he was struck by the crude technology used to evaluate the patients that he decided to develop a system for recording sensitive signals from thousands of sensors placed directly on the surface of the brain—a mission that at the time seemed "kind of crazy," he says.

Whitehead has found nanoparticles that work well for precise drug delivery.

Ultimately, one of the biggest challenges will be adapting the electronic interface so that it doesn't degrade over time. "Our bodies are full of salt water, and salt does not work well with electronics," he says. *—Amanda Schaffer*

Kathryn Whitehead

A systematic search discovered nanoparticles that could improve drug delivery.

PICTURED ABOVE

While still working on her PhD in chemical engineering at the University of California, Santa Barbara, Kathryn Whitehead created small experimental patches that, when swallowed, adhere to the intestine to deliver insulin. It is a promising alternative to the frequent painful insulin shots that people with diabetes typically need.

More recently, Whitehead has been focusing on small interfering RNA (siRNA), which can be used to target and shut off gene expression. These molecules have enormous potential for treating cancers and genetic disorders, but it's difficult to deliver them to the appropriate cells. Though embedding siRNA in a protective nanoparticle seems like a promising approach, researchers have had difficulty finding nanoparticles that can both navigate to the desired tissue and deliver the molecule across the cell wall.

Instead of trying to make educated guesses at particles that might work, as others in the field were doing, Whitehead has systematically tested thousands. While working as a postdoc at MIT's Koch Institute for Integrative Cancer Research, she screened thousands of potential

COURTESY OF KATHRYN WHITEHEAD
DATA FROM WORLD HEALTH ORGANIZATION

18 million

Number of cars sold in China in 2013

She has not had any real "eureka moments" in her lab, she says. "Perseverance is the major theme."

nanoparticles, zeroing in on the handful with the best results. Four biotech companies have since licensed Whitehead's patents in RNA delivery materials.

Now, as an assistant professor of chemical and biomedical engineering at Carnegie Mellon University in Pittsburgh, she is busy analyzing the next batch of nanoparticles and siRNA she'd like to test for various treatments, including some that target lymphoma tumors. Despite her remarkable achievements, she has not had any real "eureka moments" in her lab, she says. "Perseverance is the major theme." *—Patrick Doyle*

Hui Wu

Cheaper and more powerful batteries could help reduce China's deadly air pollution.

Hui Wu grew up in a small, quiet city in central China. Few families owned televisions in the 1980s (his was one of the lucky ones), and even fewer had cars. His mother biked to the hospital where she was a nurse. His father, a middle-school chemistry teacher, let him tag along to classes when he was eight or nine years old, sparking an interest in science and experimentation.

After earning a PhD at the elite Tsinghua University in Beijing, he went to Stanford as a postdoc, joining the lab of Yi Cui, one of the top battery chemists in the world. But later his father fell ill with lung cancer, and "as an only child, I don't think I had any choice other than to come back to help my family," he explains. In 2012, he took a job teaching and researching at Tsinghua. (His father came to Beijing to receive treatment but died last year.)

Wu uses nanostructured materials to improve the efficiency of batteries. And he feels the urgency of his quest even more back home, given the alarming levels of pollution in China's large cities. Sitting in his office on the Tsinghua campus, with a blinking battery tester beside his desk, he reflects, "When I was in California, the sky was always bright blue, but I never see skies like that in Beijing."

Longer-lasting batteries could extend the range of electric vehicles, which may be part of the solution to Beijing's smog—vehicle emissions contribute roughly a third of the fine particles that blacken the skies. Better batteries could also increase storage capacity for solar and wind power, which would make those technologies more affordable in China.

Today's consumer electronics and electric vehicles most commonly use lithium-ion batteries, in which lithium ions move between the electrodes during charging and discharging; the negative electrode is typically made of graphite. In theory, replacing graphite with silicon could vastly increase power density, giving batteries with the same weight a much longer life. But silicon swells in volume more than 300 percent as it charges, making it unstable. While at Stanford, Wu helped figure out (working in the same lab as Guihua Yu, page 55) how to use a porous polymer gel to encapsulate tiny particles of the silicon, allowing them to expand harmlessly in the space of the polymer matrix.

Wu prefers low-tech ways for himself: he lives with his lawyer wife and their toddler on the Tsinghua campus, and he rides a bicycle to his office. He appreciates practical solutions. "I don't want to create a material that's only feasible in the lab," he says. "I'm interested in using science to solve practical problems of our daily life." *—Christina Larson*

SAM KERR; COURTESY OF HUI WU
DATA FROM ENERGY INFORMATION ADMINISTRATION

Emily Balskus

More precise knowledge of the bacteria in our guts could lead to better-targeted treatments for chronic conditions.

Problem:
Some 100 trillion bacteria live in our intestines, and their activities are strongly linked to illnesses like heart disease and colon cancer—and are critical in maintaining our general health. Although we know these microbes play an essential role in metabolizing drugs and digesting food, we know relatively little about the chemical transformations they use to get the job done. Learning more about them will be essential to creating new drugs and therapies and shaping dietary guidelines for individual patients.

Solution:
Emily Balskus, an assistant professor of chemistry and chemical biology at Harvard, uses a variety of approaches, including advanced DNA sequencing, to discover new metabolic pathways and to study how gut bacteria use chemical reactions to survive. In one example of her success, Balskus's Harvard lab has been credited with uncovering the bacterial enzymes in the human gut that convert the essential nutrient choline to trimethylamine, a metabolite linked to heart disease. Because a majority of choline comes from food, learning more about its relationship to intestinal bacteria could illuminate the link between diet and the risk of heart disease. *—Kristin Majcher*

ENTREPRENEURS

FEATURING:

Miles Barr
Rand Hindi
Alex Ljung
Aaron Levie
Palmer Luckey
Michael Schmidt
Ayah Bdeir
Bret Taylor

These innovators are creating businesses that will upend markets or create new ones.

Miles Barr

The CEO of a solar startup hopes you never see his product.

PICTURED OPPOSITE

Miles Barr shows me into a hot and sunny conference room. He opens a metal case and reveals neat rows of e-readers, smartphones, and tablets.

Barr hands me two of the phones, each displaying the same colorful picture of a tree, and says one of them is getting electricity from a solar panel on its screen. I squint at them, trying to tell them apart, but I can't. The same holds for device after device in his case. Even indoors, his e-reader, which requires much less power than the phones, is getting enough energy from the see-through photovoltaic coating to make plugging it in totally unnecessary.

The see-through panels aren't yet on the market, but it's easy to tell that they'd be a hit. Although you can already buy phones with solar cells on the back, they generate power only if you leave them face down. These transparent solar cells work as you use the device normally.

Barr's solar cells are invisible because they are made of dye-like molecules that absorb wavelengths of light humans can't see, letting visible light pass right through. In 2011, he cofounded a company called Ubiquitous Energy to develop the technology, starting with solar cells that could still be seen faintly on the screen. Since then, the startup has gotten them effectively invisible and made them efficient enough for low-power applications like e-readers and watches. Now it is trying to improve the reliability of the manufacturing process so the coatings can be integrated into existing assembly lines for electronic devices.

12%
Portion of U.S. home electricity demand attributable to electronic devices

Barr pairs his inventiveness with a flair for salesmanship. In grad school he showed off solar cells printed on paper by folding the sheet into a paper airplane and attaching electrical leads to demonstrate that it could generate electricity. His demos have helped raise $8 million for Ubiquitous Energy, which recently left the Cambridge Innovation Center near MIT to set up shop in Silicon Valley.

Barr thinks he can go well beyond powering portable electronics. In his demonstration he holds up two sheets of window glass, one equipped with his invisible solar cells. By absorbing infrared and ultraviolet light, windows with this technology could help keep a room cool and generate power. *—Kevin Bullis*

Rand Hindi

Guiding your life using the power of big data.

Rand Hindi once put on more than 70 pounds just to see if data could help him take the weight off. He tracked every aspect of his life—what he ate and drank, how long he slept—and fed the results into software that determined which behaviors were bad for him. Sure enough, after heeding the software's advice, he lost the weight.

Now what Hindi wants to reduce is the "friction" of urban life. In 2012 he founded a Paris-based company called Snips, which analyzes data in hopes of making city living more efficient. For example, Snips partnered with France's national railway to create an app that predicts up to three days in advance how crowded different trains will be. By mining such sources as weather information, historical passenger counts, and real-time check-ins from users of the app, it can advise people to stay away from particular stations or guide them to trains with more seats available. Now Snips is developing ways to use an urbanite's context—location, weather, interests—and deliver useful information before he or she even asks for it. *—Suzanne Jacobs*

COURTESY OF RAND HINDI; DATA FROM FRAUNHOFER USA

Photograph by Leah Fasten

Barr holds a piece of glass coated with the invisible photovoltaic cells he developed.

Alex Ljung

SoundCloud is changing how music gets made.

Q: How did you come to create a service that is like a YouTube for music, letting people upload and embed tracks, find new artists, and leave comments while listening to songs?

A: After high school, I started working as a sound designer in a postproduction studio in Stockholm. I would do sound effects and music for movies and for TV. [When] I started studying engineering at the Royal Institute of Technology in Stockholm, that's where I met Eric [Wahlforss], my cofounder, who it turned out had a very similar background. We were both recording and creating music and sound, and we just didn't have a good way of being able to share it with each other and then get some feedback on it.

Q: In the beginning, a small group of musicians used SoundCloud to share their songs. Now it reaches more than 250 million listeners per month. How are they using it?

A: What's really cool about it is that it affords a lot of different user experiences. We have somebody who might just open up their phone and say "Oh great, there's a brand-new track from 50 Cent. I just want to listen to this one now and enjoy it." And then on the other side of the spectrum, you have these more intense engagements. Snoop Dogg has used it to find a bunch of artists that he wants to work with. He found this artist Iza Lach from Poland and signed her to his record label.

Q: How is this reshaping the music business?

A: We have people who could be anywhere in the world at the moment, creating a completely new genre that hasn't been known before, and within a very short amount of time, that may be the biggest thing in the world. I still think it's amazing that not even two years ago Lorde was just a young artist in New Zealand that nobody knew of. And [after releasing her first songs through SoundCloud] all of a sudden she's one of the largest stars in the world, topping all the charts. That kind of speed is something that is really interesting. *—Kristin Majcher*

COURTESY OF SOUNDCLOUD

The Rift, shown here in a rendering, has inspired Sony to make a rival device.

Aaron Levie

The founder of Box wants to reconfigure the way we work.

He has come a long way since the fifth grade, when he sold cloth bags filled with rice as heating pads to soothe sore muscles—only to recall the product when the twist ties used to seal the bags burst into flames in customers' microwaves. Today, Aaron Levie is CEO of Box, a company that he founded in 2005; it is now on the verge of an IPO.

Box is often described as being like Dropbox for businesses: it makes it easy to store files in the cloud. But Levie envisions something bigger than mere file sharing. Because Box offers features such as electronic signatures and tools that aid regulatory compliance, he views it as a platform for connecting people not just inside companies but also across entire industries—suppliers, partners, customers, contractors, and so on. "Maybe we can save 10 percent of an employee's time, but the organization as a whole is moving 20 percent faster, and it's working with a new network of partners," he says. "At each level the change becomes more transformative."

$124 million
Box's revenue last year

High-profile clients such as General Electric validate the power of this idea. The sprawling company is using Box to keep employees in 170 countries on the same page. *—Ted Greenwald*

Palmer Luckey

If you can make virtual reality affordable for consumers, things fall into place.

Palmer Luckey, 21, grew up mesmerized by the transcendent virtual reality depicted in *Star Trek* and *The Matrix*. But when his video screen faded to black, he was back in the real world, where virtual technology remained trapped in niche applications.

So Luckey, a self-taught engineer who had been exploring technology journalism in college, began tinkering. In 2009 he hacked together his first prototypes of a virtual-reality headset in his parents' basement. He eventually called it the Oculus Rift and posted designs to Internet forums. In 2012, John Carmack, the creator of the Doom and Quake video-game franchises, took notice, and the two began an online dialogue. Luckey sent Carmack a prototype, which Carmack demonstrated at the E3 video-gaming conference. Then things really heated up. Luckey tried raising $250,000 for Oculus Rift on Kickstarter and got $2.5 million. A year later Oculus, based in Irvine, California, received $91 million in venture capital. Software developers began producing games for the Rift, which is expected to hit the market by 2016 for about $300. And in March, Luckey sold his startup to Facebook for $2 billion.

"Virtual reality isn't the next platform, it's the final platform. You won't need to perfect any other platform."

For Luckey, it's just a matter of reality finally catching up with the imagined possibilities. "The sale might have been mind-boggling two years ago," he says. "It's less so now after we've shipped about

Michael Schmidt

There aren't enough data scientists to go around—unless you automate them.

Problem:
Demand for statisticians and data experts outstrips supply. The shortfall in the U.S. alone could reach 190,000 workers by 2018, according to estimates by McKinsey & Company.

Solution:
Michael Schmidt has created an automated data scientist that can take in observations about the world and spit out theories to explain them.

Schmidt showed it could be done in 2009. He then wrote software that could examine raw data and derive laws of physics, like the one that describes the swinging of a pendulum.

Since then Schmidt has refined the software, named Eureqa, so that it can handle more than just physics questions: astronomers have used it to characterize galaxies, and doctors have used it to predict which children will have acute appendicitis. Since 2011, Schmidt has been running a startup, Nutonian, that offers the software to business users who aren't math experts. It hopes to win over businesses like the retailer Lowe's, which has piles of sales data and yearns to uncover equations that might help it sell more gas grills or two-by-fours. "The people with the skills are going to Google or SpaceX or to Wall Street, not to home-improvement chains," says Schmidt. "Our mission is to help with that, and show that you don't need to be a data scientist to make useful discoveries."

—Antonio Regalado

COURTESY OF OCULUS VR; COURTESY OF BOX; SAM KERR
DATA FROM BOX'S IPO FILING

438,404

Possible creations with the LittleBits starter kit

70,000 development kits. It's very clear that virtual reality is going to take off. I think people are going to look back and actually think it was a very low price to get a foot in the door on that VR future.

"We're going to get to the point where virtual reality is indistinguishable from reality itself. And much sooner than that, we're going to have the visual side indistinguishable from reality. It's going to take longer to get all of the other senses working, but it's a clear path. What we say around the office is: virtual reality isn't the next platform, it's the final platform. Once it's perfect, you won't need to perfect any other platform. That's going to change the way artists work with content and how they create.

"This is beyond gaming. You can have education. You can put people anywhere in the world, not just as it exists today, but as it existed in the past. You can put people in a concert, you can put people courtside at any sports game, you can hover above the playing field. Things are a long way off in terms of being perfect, but we have a road map." *—Adam Popescu*

Ayah Bdeir

Electronic blocks that link with one another also connect art and engineering.

Growing up in Beirut, Ayah Bdeir was taught that art and engineering occupied separate realms. "In Lebanon, as in most of the world, there is little blurring of the boundaries between the professions: doctor, teacher, scientist, and designer exist in separate silos," she says. The company she founded in 2011, called LittleBits Electronics, goes against that idea by making technology accessible across all disciplines and ages. It sells a library of modular electronic units that can be easily connected for projects as diverse as a sound machine, a night light, or a lifelike robotic hand.

> "It doesn't matter who you are or how you use it. Every person will find what they want."

$15 million
Venture funding raised by Quip

LittleBits makes roughly 50 different modules, which cost up to $40 each or come in kits of $99 and up. Each module is a thin rectangle measuring between one and four inches in length and containing complex hidden circuitry. Blue modules provide power. Pink ones allow for inputs, like switches, microphones, and motion sensors. Green ones are for outputs like lights, motors, and speakers. Orange ones provide wires or logic functions. Bdeir designed all the modules so they fit together magnetically, ensuring that users join circuits correctly.

Her New York–based company has sold hundreds of thousands of units in about 80 countries, and Bdeir takes pride in the fact that the product appeals to girls and boys, children and adults, designers and engineers. "A screwdriver is a screwdriver for everybody," she says. "It doesn't matter who you are or how you use it. Every person will find what they want."

—Amanda Schaffer

Bret Taylor

The former CTO of Facebook is reimagining the word processor.

At 34, Bret Taylor already has one of the most impressive résumés in Silicon Valley. He has been a creator of Google Maps; a cofounder of FriendFeed, one of Facebook's earliest acquisitions; a creator of Facebook's ubiquitous "Like" button; and Facebook's chief technology officer. He is one of those rare engineers who are equally comfortable writing code and taking a stage to tell people about it.

Yet even the best engineers and entrepreneurs mess up, and that's where my mind went when I learned of Quip, his latest venture. Quip is rethinking the word processor and other aspects of the "productivity software" that Microsoft has dominated for a generation. Apple and Google have made small inroads into Microsoft's Office empire during the past half-decade, but their marketing and software development budgets are effectively unlimited. Why would a startup try it?

Taylor understands—even embraces—the skepticism. But what gives Quip a chance against the likes of Microsoft, Apple, and Google is that the rapid shift from desktop and laptop PCs to tablets and smartphones is changing what consumers want from their software, and Quip wasn't conceived for a desktop- or laptop-dominated world. It is meant for people who often collaborate on documents while away from a desk in a traditional office, possibly on many separate devices over the course of a day (see "10 Breakthrough Technologies: Mobile Collaboration," May/June). Today, we might use a combination of e-mail, file attachments, and instant-messaging streams to deal with this. Quip puts all those functions in one place, keeping track of who changed what in a document and who said what about those changes. It makes it possible to have quick back-and-forths with a group of people without dragging them into a meeting room or setting up a conference call.

Many people thought Taylor was being irrational when he left Facebook. Though he'd made millions in its IPO, he left more on the table by leaving. But Taylor knew exactly what he wanted next on his résumé. "I had influence at Facebook," he says, "but at the end of the day I was executing someone else's strategy."

—Fred Vogelstein

COURTESY OF LITTLEBITS; COURTESY OF QUIP
DATA FROM QUIP AND LITTLEBITS

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MIT Technology Review
BUSINESS REPORT

Data-Driven Health Care

New technologies promise a flood of molecular, environmental, and behavioral information about patients. Will all that data make medicine better?

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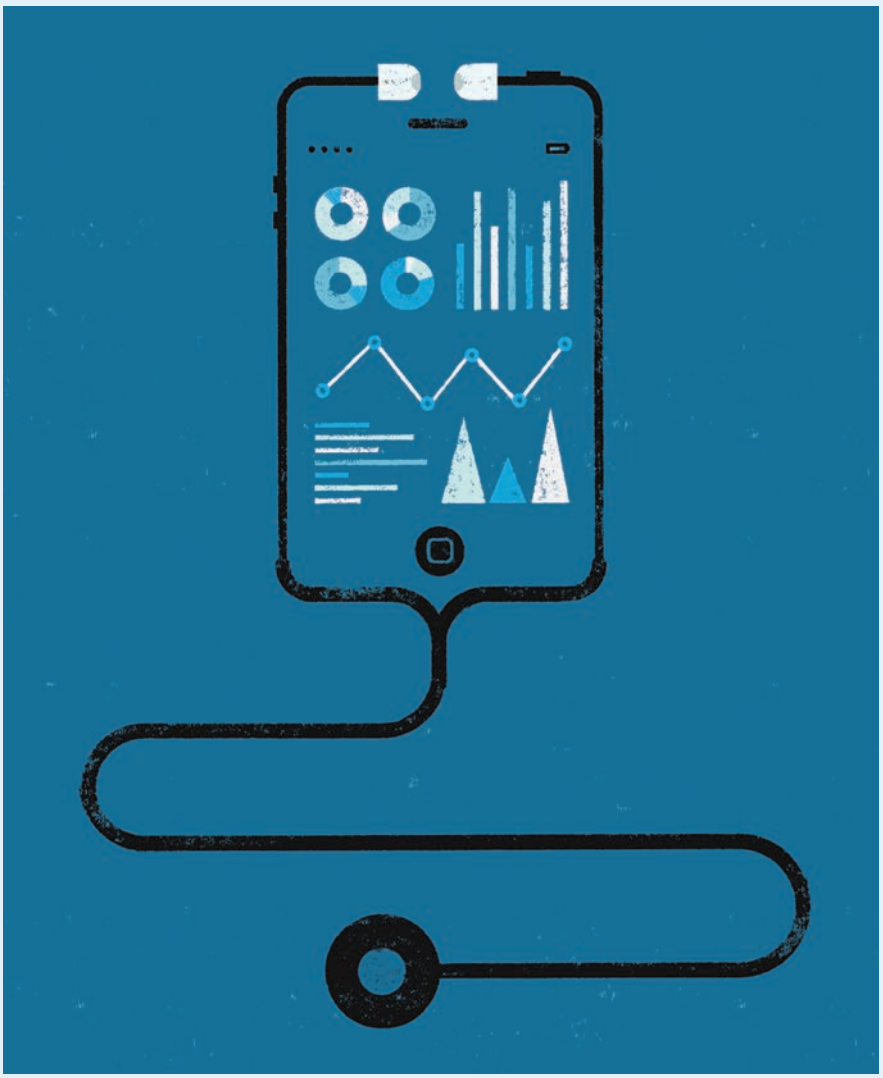


MIKE MCQUADE

The Big Question

Can Technology Fix Medicine?

Medical data is a hot spot for venture investing and product innovation. The goal: better care.

● After decades as a technological laggard, medicine has entered its data age. Mobile technologies, sensors, genome sequencing, and advances in analytic software now make it possible to capture vast amounts of information about our individual makeup and the environment around us. The sum of this information could transform medicine, turning a field aimed at treating the average patient into one that's customized to each person while shifting more control and responsibility from doctors to patients.

The question is: can big data make health care better?

"There is a lot of data being gathered. That's not enough," says Ed Martin, interim director of the Information Services Unit at the University of California San Francisco School of Medicine. "It's really about coming up with applications that make data actionable." →

The business opportunity in making sense of that data—potentially $300 billion to $450 billion a year, according to consultants McKinsey & Company—is driving well-established companies like Apple, Qualcomm, and IBM to invest in technologies from data-capturing smartphone apps to billion-dollar analytical systems. It's feeding the rising enthusiasm for startups as well. Venture capital firms like Greylock Partners and Kleiner Perkins Caufield & Byers, as well as the corporate venture funds of Google, Samsung, Merck, and others, have invested more than $3 billion in health-care information technology since the beginning of 2013—a rapid acceleration from previous years, according to data from Mercom Capital Group.

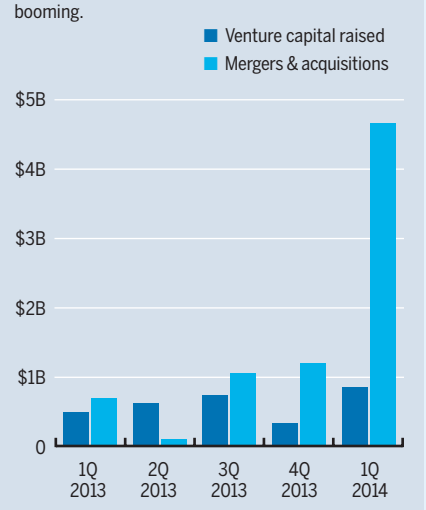
This *MIT Technology Review* Business Report looks at the technologies and companies most likely to survive the boom and the challenges they will face as they push to remake health care.

The groups that control the most medical data today are insurance companies and care providers, and their data analysis is already beginning to change health care. Express Scripts, which manages pharmacy benefits for 90 million members in the U.S. and processes 1.4 billion prescriptions a year, has scoured its data from doctors' offices, pharmacies, and laboratories to detect patterns that might alert doctors to potential adverse drug interactions and other prescription issues. Doctors can now know 12 months in advance, with an accuracy rate of 98 percent, which of their patients may fail to take their medicine. Taking steps to avert that problem could improve patients' health and reduce the $317 billion spent in the United States each year on unnecessary ER visits and other treatment.

Today many companies and health-care providers are adding other layers of information to create an increasingly precise, patient-specific brand of medicine. New mobile technologies, for example, could provide information about a patient's everyday behaviors and health, creating opportunities for care providers to influence patients far more frequently. Data brought in from electronic health records would add doctors' insights, test results, and medical history. Genetic data would offer insight into whether patients are predisposed to certain conditions or how they might react to treatments.

Investor Enthusiasm

Global deal-making involving health-care IT firms is booming.



"We want to believe that most of the things we do in medicine are based on evidence," says Malay Gandhi, managing director of Rock Health, which funds health-care startups. "Some are, but most aren't." The opportunity, he says, is that medicine could become more analytical and evidence-based.

100,000
Number of health apps available for smartphones

Data is also changing the role of patients, offering them a chance to play a more central part in their own care. One way is by using mobile technology to monitor sleep patterns, heart rate, activity levels, and so on. In development are even more advanced devices capable of continuously monitoring such key metrics as blood oxygen, glucose levels, and even stress. And companies like Apple are hoping to become repositories for all this information, giving consumers new ways to track and perhaps improve their health.

This kind of information may be useful and interesting for anyone, but it can become essential for the millions living with chronic conditions like diabetes, heart disease, and depression. WellDoc makes a prescription-only FDA-approved "patient coaching" system, which advises users on how much insulin they should take in light of information recorded on their smartphones: blood sugar levels, recent meals, and exercise. It also offers tailored messages of encouragement and provides the patient's doctor with treatment recommendations based on the data and established medical guidelines. A feature under development would enable the system to predict a hypoglycemic reaction and help users avoid it.

Ginger.io uses data collected (with permission) from a phone and other sensors to assess the behavior of people with mental illnesses such as depression. Are they calling loved ones, or getting enough sleep? When a patient is showing signs of struggling, someone can be alerted.

Over time, both companies will aggregate this information to help doctors study and improve treatment overall. "It's like one of the largest clinical trials in history," says Chris Bergstrom, WellDoc's chief strategy and commercial officer. "And it's not even in an artificial environment—it's in real time."

Families affected by Phelan-McDermid syndrome, a rare condition in which a deletion on chromosome 22 causes problems such as learning and memory deficits, are building a database of information from genomic tests, clinical medical records, extensive family surveys and histories, and more. The goal is to create a central repository where researchers can examine multiple sources of data simultaneously. That's increasingly important as researchers begin to see connections between Phelan-McDermid, autism, and other conditions. Another benefit: data that once would have been locked up in one academic researcher's lab will now be readily available to many different experts.

"So much of that data is already out there," says Megan O'Boyle, whose daughter Shannon was diagnosed in 2001, just two years after chromosome 22 became the first human chromosome to be sequenced. "It's just sitting there waiting to be used." —*Nanette Byrnes*

SOURCE: MERCOM CAPITAL GROUP

Q + A

More Phones, Fewer Doctors

VC legend Vinod Khosla believes that medicine will go mobile and most doctors will be out of a job.

● Famous as the founding CEO of Sun Microsystems, Vinod Khosla has spent the past 28 years as a venture capitalist. As a partner at Kleiner Perkins Caufield & Byers, he was involved in some of the technologies underpinning the Internet. Now 59, he is currently head of Khosla Ventures, where he sees a similar opportunity in medicine and is investing in digital health ventures that he predicts will reinvent the field. In June, he spoke to editor in chief Jason Pontin at the *MIT Technology Review* Digital Summit in San Francisco. Making no apologies for having picked some losers, including some of his high-profile bets on clean tech, he declared, "I don't mind failing, but if I am going to be successful, it better be consequential."

Here is an edited version of the full interview.

"Much more precise medicine is possible. And I for one want it. Because our smartphones are on us 24/7, we can start to do much more." —Vinod Khosla

What surprised you the most when you turned your attention to health care?
What surprised me initially was how bad it was. Researchers gave the same data to 40 cardiologists and asked the same question: "Should this person have cardiac surgery or not?" Half said yes and half said no. Whether you get surgery depends on which doctor you happen to pick? That is pretty bad. And that's not the worst part. Two years later they took the same data to the same cardiologists, and 40 percent changed their mind. I could give you 100 examples like that.

You have concluded that about 80 percent of what doctors do can be replaced by machines. So tell me which things we can replace, which things probably should remain human, and why.
Atul Gawande is one of the most famous surgeons. He said machines are much better at the cognitive parts of medicine: diagnosis, writing the right prescriptions. On purely ethical questions, or comforting, humans can do much better. That raises a question that I always ask and that pisses the physicians off. If you want the human element of care, shouldn't we use the most humane humans?

Doctors don't always qualify.
It's hard to get into good medical schools. You select for IQ and hard work. You don't select medical school students for compassion. I think the role has yet to be defined. I'm not saying humans have no role. If you ask people in the burn unit of the hospital, do we need doctors there? Absolutely. Whether human plus computer is better—whether in certain parts of the world where there is no doctor for 50 miles, the machine will do much better—it's hard to predict.

You have invested in a number of mobile health companies like CellScope, the maker of a smartphone attachment which allows you to peer into the ear, that place the responsibility for health care on the individual. Do people really want that?
Yes. I've often said our goal in medicine should be to make the consumer the CEO of his own health. By that I don't mean the consumer should do his own diagnosis. But every home should have a digital first aid kit that has half a dozen to a dozen devices that let you take your ear image like CellScope, or let you take your EKG like AliveCor [another Khosla investment], or a dermatology image if you have a mole.

With the result being better medicine?
Much more precise medicine is possible. And I for one want it.

Because our smartphones are on us 24/7, we can start to do much more. Take psychiatry. We have a company called Ginger.io that monitors your cell phone with your permission. They collect thousands of data points a day. They figure out over a period of time what day of the week you call your mom. What you do on Thursday evening. Do you call your friends to make plans for the weekend? It figures out that this week you didn't eat. You didn't go from your bedroom to your kitchen. Your cell phone can tell that. They've discovered hundreds of new microbehaviors that can actually be predictive [of mental state]. If you can monitor people 24/7, you can move them from whatever stage of illness to be more healthy. I think that will become possible.

Wellness will become the point of health care. Today it's just sick care.

Data Analysis

IBM Aims to Make Medical Expertise a Commodity

Big Blue thinks its *Jeopardy!* champion Watson can make money by offering health-care providers new expertise without hiring new staff.

● U.S. cancer care is headed for a crisis, warned the American Society of Clinical Oncology in March. Cancer cases are projected to soar 42 percent by 2025 as America's population ages, but the number of oncologists trained to treat them will grow by only 28 percent. That →

WIKIMEDIA COMMONS

mismatch is likely to exacerbate existing inequalities in care between the fraction of patients treated by specialists at major academic centers and the many more who get care at community clinics or hospitals, mainly from general oncologists.

Enter a game show champion to save the day.

An attempt to transform cancer care is a major part of IBM's efforts to make money from its *Jeopardy!*-winning Watson software. The company aims to offer health-care organizations a cheaper way to improve care by turning oncology expertise into a commodity.

This effort to break humans' monopoly on cancer expertise is the advance guard of a model that IBM hopes it can eventually roll out across many areas of medicine. It is also the first real test of the company's claims that Watson can move beyond *Jeopardy!* and earn money.

Whether Watson passes the test could be critical to IBM. The company's revenue has declined for two years as technology's shift to the cloud has left some of its core products behind. CEO Ginny Rometty's promise to spend $1 billion on a new business group dedicated to commercializing Watson is just about the only turnaround prospect in sight.

IBM and collaborators are building two versions of Watson trained in oncology. Memorial Sloan Kettering Cancer Center, in New York, is beta-testing a version for lung, colorectal, and breast cancer. The University of Texas MD Anderson Cancer Center, in Houston, began using one this summer to advise its new fellows on treatments for leukemia. Both versions help oncologists decide on a treatment plan by ingesting the patient's medical records and pairing that information with knowledge from medical journals, textbooks, and treatment guidelines.

80%

Proportion of data that is unstructured, coming from e-mail messages, photos, and doctors' notes

Lynda Chin, a professor of genomic medicine at MD Anderson and a leader of the center's Watson project, anticipates that in the future that kind of product will be highly valued by general oncologists and regional cancer practices. "Physicians are too burdened on paperwork and squeezed on revenue to keep up with the latest literature," she says. That limits the care physicians can deliver, and it has financial consequences: "If you can't make a decision based on your own knowledge, you have to refer the patient out, and that's going to hurt your bottom line."

A version of Watson to be tested this year with brain tumor patients from the New York Genome Center aims to provide oncologists with deep expertise in the new field of genomic medicine that would otherwise be expensive to obtain. This incarnation of Watson suggests treatment options based on details of the mutations detected in a person's tumor by genomic sequencing. Using genome sequencing to direct cancer treatment is just becoming feasible thanks to the plummeting cost of the technology. But in practice, the challenges of interpreting genomic data keep it beyond the reach of most oncologists and clinics.

"Physicians are too burdened on paperwork and squeezed on revenue to keep up with the latest literature."
—Lynda Chin
Professor of Genomic Medicine, MD Anderson Cancer Center

"It requires a heroic level of expertise and is entirely manual," says Ajay Royyuru, director of the computational biology center at IBM's Yorktown Heights lab. Doctors must chase down relevant research papers for the mutations they find in a patient's tumor, try to understand how the mutations change the cancer cells' physiology, and then work out which treatments could target the malfunctioning processes. Getting from a genome sequence to a treatment decision can take five to 10 months, says Royyuru—time that cancer patients can ill afford.

Using Watson, it takes minutes. Doctors need only load in the genomic data. A schematic is then generated showing which of the molecular processes inside a cell have been altered. An oncologist can explore those findings and click a button to see a list of possible treatments that would target the problem pathways.

Though technologically impressive, the Watson cancer projects are not yet contributing materially to IBM shareholders or helping many cancer patients. Although the deals with medical centers are intended to lead to marketable products, they are for now R&D investments, says Michael Karasick, who leads R&D for the Watson group and was previously director of the company's research lab in Almaden, California. "Revenue comes when the product hits the market," he says.

Some already have. For example, a Watson-based system for the medical insurer Wellpoint helps preauthorize requests for medical procedures. But Watson-based medical products haven't been hitting the market at the rate IBM seems to have expected. A document leaked to the *Wall Street Journal* in January said that the Watson unit was falling behind on a projection that it would bring in $1 billion in revenue by 2018.

One problem is that Watson has struggled to accurately understand technical information. It's been flummoxed by medical jargon, the different ways researchers refer to the same thing in journal articles, and sloppy grammar in doctors' jottings on patient files. Clinicians have had to spend more time than anticipated teaming up with IBM software developers to chase down the misunderstood acronyms or wrongly parsed sentences that caused Watson to misinterpret medical records or suggest incorrect treatments.

Michael Witbrock, vice president of research at the artificial-intelligence company Cycorp, says that IBM's *Jeopardy!* winner was always going to need significant engineering to become an expert in

COURTESY OF MD ANDERSON CANCER CENTER

any specific area. The game show calls for a mastery of general knowledge at a shallow level, not the kind of deep, layered expertise needed to treat cancer. "They went after industrial scope, not industrial depth," says Witbrock.

Eric Brown, director of Watson technologies at IBM's Yorktown Heights lab, says major changes to Watson, informed in part by feedback from the cancer projects, have helped it adjust to its new work. Although there is still a human training process, improved machine learning means Watson now requires less training to get good results, he says.

A company getting started with Watson today can make use of interfaces including one that involves clicking thumbs up or down next to its answers to test questions. In addition, a new team within IBM's technical assistance group is dedicated to helping customers prepare data and use it to train Watson. Late last year the company launched a cloud-based platform where products can be built without having to bring IBM technology on site.

One thing those technical improvements haven't done is shed any more light on whether renting out software that acts like a medical specialist can be a big business. Some people in the health-care industry are unsure.

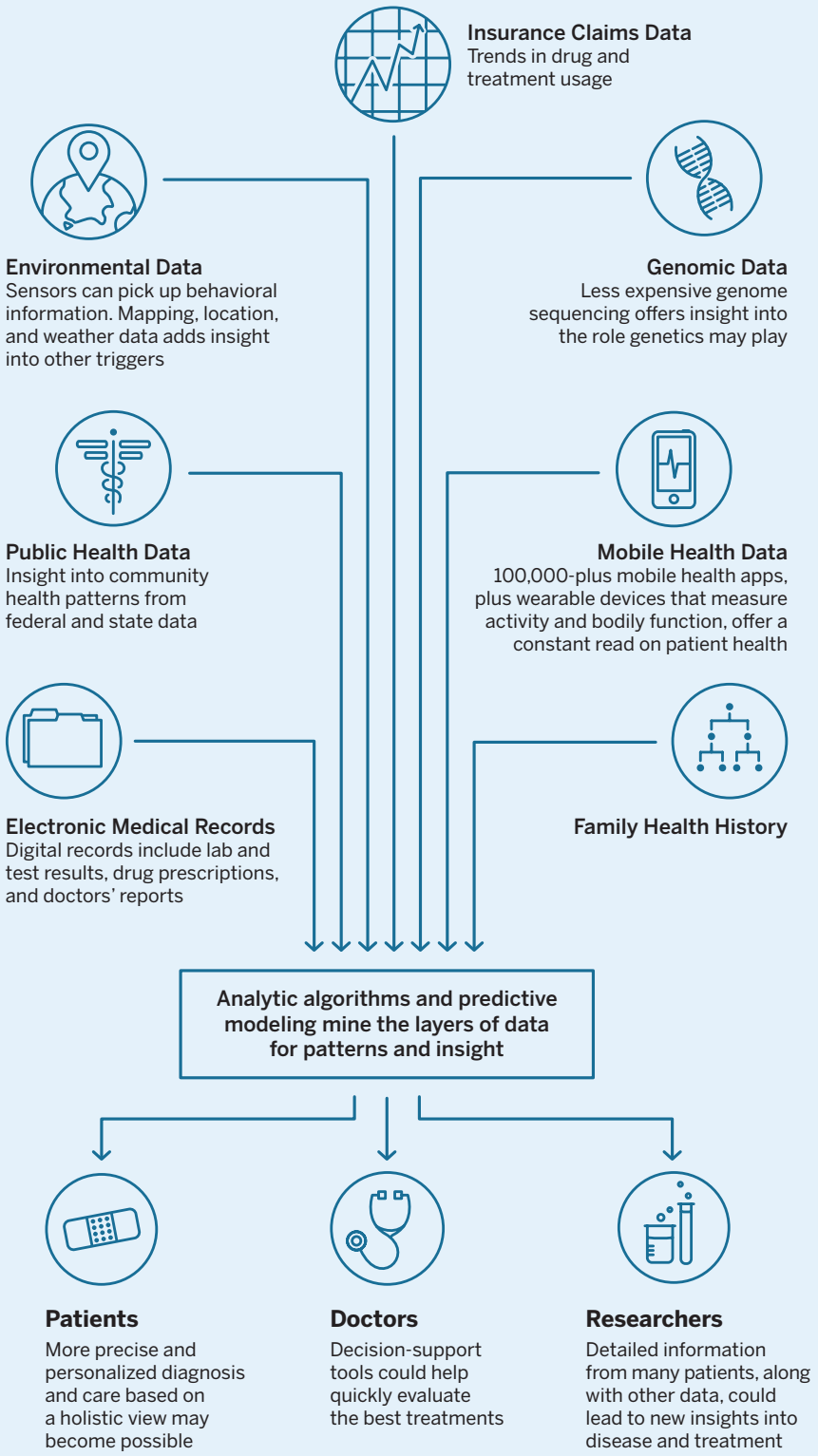
The most successful products built on advanced data processing historically have been focused on managing costs and efficiency in populations of many patients, not improving what doctors do with individuals, says Russell Richmond, a board member for the health-care data company Explorys and previously CEO of McKinsey's health-care division, Objective Health.

That kind of product speaks directly to profit margins and is in fact explicitly encouraged by the Affordable Care Act, which is reshaping the U.S. health-care industry. How products like the Watson-powered cancer advisors will make money is less clear. As Richmond puts it: "Helping a cancer patient get the best treatment is really good for humankind, but it may not generate a lot of profit."

—Tom Simonite

The New Medical Data Ecosystem

Medical data is being captured today from many sources. Pulling it together and studying what it means is the next challenge.



Genomics

23andMe Tries to Woo the FDA

The DNA testing firm hopes a more coöperative approach with regulators will get its business back on track.

● Anne Wojcicki bounds into a conference room in Mountain View, California, straight from a five-mile ride from home on an elliptical bike. The 40-year-old cofounder and CEO of the consumer genetic testing firm 23andMe is breathless, and not just because of the workout. On this warm day in mid-June, Wojcicki is "super-excited" about an announcement scheduled for two days hence: the Food and Drug Administration has agreed to review a health-related genetic report the company wants to make available to customers.

It's the first step out of the FDA's doghouse for 23andMe. For $99, the company analyzes key components of a person's DNA from a vial of saliva, but last November the federal agency issued a testy warning letter barring it from marketing its service. The FDA said that by selling consumers a test and health reports that outlined their chances of getting dozens of diseases, plus their likely response to various drugs, 23andMe was effectively selling a medical device. That requires explicit approval—and the FDA said 23andMe hadn't come close to providing enough evidence that its test provides accurate, reliable health assessments.

The FDA allowed the company to keep selling the test as long as it provided only raw genetic data and ancestry information, nothing on disease. Sales slowed. Evidently, people care much more about their chances of getting Alzheimer's than about how much Neanderthal DNA they have. "A lot of companies would shut down in this situation, but we looked at how do we double down," Wojcicki says between sips from a water bottle. That meant talking frequently with the FDA, marshalling more data to support health claims, and hiring a number of executives experienced in medical devices.

230
Average number of studies in which a consenting 23andMe customer's genomic data is used

The company's plight reflects just how challenging it is to translate genetic data into useful medical information. Though the company encourages customers to seek a doctor's advice, making medical decisions based on tests like those from 23andMe carries risk. Current understanding of genetics' role in disease is far from complete, often not conclusive, and potentially misunderstood, says George J. Annas, chair of the department of health law, bioethics, and human rights at Boston University's Schools of Public Health, Medicine, and Law.

Nevertheless, some experts say it's up to consumers to decide how to use the data, and that access to genetic data and information on what it might mean is a basic right. "It's no different from a family history," says Lawrence Lesko, a 20-year FDA veteran who is now director of the University of Florida's Center for Pharmacometrics and Systems Pharmacology.

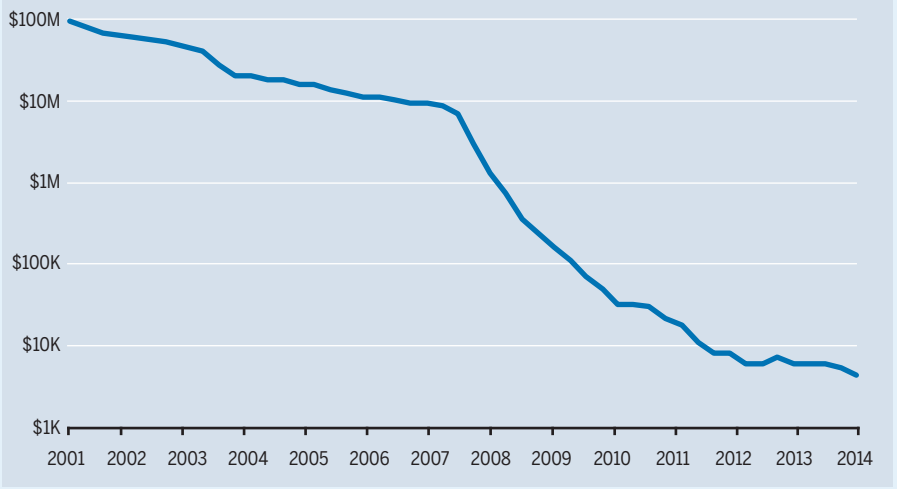
At times 23andMe has hurt its own cause. A year after submitting applications for seven health reports in 2012, it stopped communicating with the FDA for six months, according to the agency, at the very time it prepared to launch a television ad campaign. That's what prompted the FDA to clamp down.

The company, which has raised $126 million in funding, needs to fix its FDA issue if it is to meet its goal of creating a database of as many as tens of millions of genetic profiles, up from 700,000-plus today. Coupling those profiles with data from customer health surveys could entice pharmaceutical and medical-device companies to pay 23andMe for the chance to look for connections among gene variations, diseases, and drug response at a small fraction of the cost and time needed to do traditional clinical trials. Genentech has already paid the company to help it recruit breast cancer patients who had taken its drug Avastin in order to assess their response. The strategy of crowdsourcing big data echoes that of one of 23andMe's big investors: Google, which was cofounded by Wojcicki's husband, Sergey Brin. (They separated last year.)

Even before last November's letter, the challenges of meeting regulatory requirements had already prompted 23andMe's U.S. rivals to exit the market for direct-to-consumer genetic tests. Other testing firms bypass the FDA by selling through doctors. If 23andMe can't get FDA approval on at least some health reports, that could spell the end of selling genetic informa-

DNA Data for All?

The cost of sequencing a human genome has dropped.



SOURCE: NATIONAL HUMAN GENOME RESEARCH INSTITUTE

tion directly to consumers within the U.S., says former FDA counsel Patricia Zettler, a research fellow at Stanford Law School.

To win over the FDA, Wojcicki is first shepherding one specific health report—for Bloom syndrome, an inherited disorder that often results in deadly cancer by the mid-20s—through the approval process for medical devices. If it works, it would provide a template. But since 23andMe originally offered more than 200 health reports, it's not yet clear that this process will be enough to attract large numbers of new customers.

Zettler is one of many observers who think 23andMe will eventually get through the FDA process, at least on individual health reports. But the FDA is contemplating new hurdles, like requiring that claims be reviewed by an expert panel.

Wojcicki wonders if too many limitations will simply spur people to take their genetic data to Canada or China for interpretation. "How do you regulate information?" she asks. "I'm not sure you can hold it back." *—Robert D. Hof*

Mobile

Mobile Health's Growing Pains

Full of promise, mobile health still needs to wow patients and nail down its payoff.

● Among technologists, mobile health is thriving. Since the start of 2013, more than $750 million in venture capital has been invested in companies that do everything from turn your smartphone into a blood pressure gauge to snapping medical-quality images of the inner ear. Apple, Qualcomm, Microsoft, and other corporate giants are creating mobile health products and investing in startups.

The idea is straightforward: the increasing number of smartphones means that small, inexpensive sensors, low-energy Bluetooth, and analytic software make it possible for patients and doctors to capture all kinds of data to improve care. Patients can play a more active role in their own health. Doctors and nurses can make house calls without ever leaving the office.

One crucial group, however, remains unsold: the patients. Though one in 10 Americans owns the type of tracking device made by Nike, Fitbit, and Jawbone to monitor steps taken, quality of sleep, or calorie intake, more than half of those devices are no longer in use, according to Endeavour Partners, a consulting firm. Of the 100,000-plus mobile health applications available for smartphones, very few have been downloaded even 500 times. More than two-thirds of people who downloaded one have stopped using it, according to a 2012 study done for the global accounting firm PWC.

"There are unrealistic expectations for when and how mobile health is going to come together," says Patty Mechael, former executive director of the mHealth Alliance, which helped develop early standards for mobile health technologies. In the ⟶

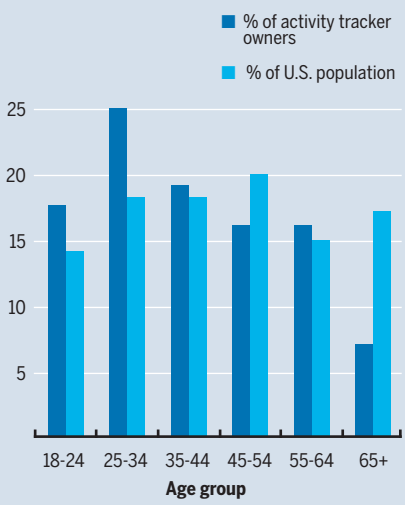
Mobile Health-Monitoring Devices

There's been an explosion in smart devices that measure and monitor various bodily functions. **BY RACHEL METZ**

COMPANY	Propeller Health	CellScope	Google	Withings	Kolibree
FEATURES	Propeller sensor attaches to an inhaler used for asthma or chronic obstructive pulmonary disease and tracks when and where the inhaler is used.	Diagnostic devices that attach to smartphones; the first is a digital otoscope that works with an app to let you view and record images of the inside of the ear.	A contact lens with a circle-shaped layer of electronics for testing the level of glucose in tears—potentially useful for people with diabetes.	The Pulse O_2 includes an optoelectronics sensor and green and red LEDs to measure heart rate and blood oxygen level. An accelerometer tracks activity and sleep.	An electric toothbrush equipped with an accelerometer, gyrometer, and magnetometer to track brushing habits, plus smartphone games controlled by brushing.
STATUS/PRICE	Received FDA approval in May.	Price is yet to be determined. Expected to be available sometime this year.	Google is talking with the FDA and intends to find partners to make it.	$120	$129–$199; three replacement brush heads $20 to $25. Expected in late 2014.
DATA SHARING	Users decide what's shared with doctor and whether to share anonymously to help identify asthma hot spots and triggers.	Users can upload ear videos to a CellScope site, where a doctor can see them.	N/A	No data communicated, though data could be shared with your doctor.	You can choose to share data with your dentist.
FINANCIAL BACKERS	Kapor Capital, the Social+Capital Partnership, Calif. HealthCare Foundation	Khosla Ventures, Rock Health	N/A	360 Capital Partners, Ventech Capital, Idinvest Partners, Bpifrance	Angel investors

Stepping Up

Younger age groups are more likely to own an activity tracker.



U.S. "we are somewhere between the peak of the hype cycle and the trough of disillusionment," she says.

Enthusiasm has been slow to build in part because the technology is often still not perfect, with seemingly simple functions like step counters lacking precision. Another problem is motivation. Many people simply don't seem to like using these apps and devices. It is clear, though, that a well-designed mobile health system can help if patients use it.

At the Center for Connected Health at Partners HealthCare, a health-care network that includes Boston's two leading hospitals, Brigham and Women's and Massachusetts General, a number of mobile programs have been shown to offer strong payoffs both in quality and cost.

One recent study tested whether mobile phones could help increase activity among patients with diabetes. It's an important way to combat the disease's progression, but it's something traditional programs have had little success achieving. Of a group of 130 patients with diabetes, half were given Fitbit activity monitors. By combining feedback from the Fitbit with existing patient records, an algorithm determined which text messages would be sent to the patients. Those falling behind on their goals got messages of encouragement; some messages included information about nearby Zumba classes or jogging paths, based on location data picked up from the patients' mobile devices. On rainy days, the program might send a note about ways to exercise indoors.

Doctors received progress updates via a stoplight system displayed on the patient's electronic medical record. Green meant the patient was doing well. Yellow was caution. Red signaled the patient was not responding to the text messages.

After six months, the average patient was walking about a mile farther each day. In addition, the patients' blood sugar control improved significantly—better results than might be expected with some FDA-approved drugs, says Kamal Jethwani, a doctor who ran the study as the center's leader of research and program evaluation.

For Partners, the program is successful on two counts: patients are healthier, and the cost of caring for them is lower. The payoff for better managing a chronic disease like diabetes comes over many years, but in Jethwani's study, a number of patients have already had drops in blood sugar that equate to savings of $1,000 to $1,200 in doctor visits and other treatments. That's a strong return on a program that costs $300 per patient to run, notes Jethwani.

These are the kinds of results that have enthusiasts convinced that mobile technology can not only fundamentally overhaul how health care is delivered, but also offer sufficient financial benefit to convince insurers and patients to pay for it.

John M. Halamka, a professor at Harvard Medical School and chief information officer of Beth Israel Deaconess Medical Center, expects this kind of technology-enabled monitoring to become standard practice within the next few years. One sign that a heart patient may be about to have a problem is rapid weight gain, he notes. A smart scale that picks up on that could trigger a quick intervention from the doctor and avoid a visit to the ER.

At the University of California, San Francisco, which recently announced an initiative to begin testing the effectiveness of mobile devices in health care, one of the biggest technological achievements to date was simply starting to get doctors to move beyond pagers. Now doctors access patient messages via a mobile or Web application, and the message automatically becomes part of a conversation. Under the new system, the whole care team is aware of what is happening, and the doctor has the patient's history available when fielding questions. Getting mobile health technology right can be tricky, however. Fitbit makes some of the most popular activity trackers, but in February the company voluntarily recalled its top-of-the-line $129 Fitbit Force after users complained of skin irritation from the wristband. More serious technological problems have sidelined devices aimed at difficult tasks like measuring blood glucose levels without drawing blood, a desirable feature for people with diabetes.

For all the challenges in mobile health, one issue that dominates many discussions about the technology may fade rather quickly. Privacy concerns have yet to come up in the Partners trial, says Jethwani. "I've never heard any patient say, 'How do you know so much about me?' or 'Why do you know so much?'" he says. "Instead, they say 'Now that you know all this about me, can you give me more useful information?'"

—Nanette Byrnes

C8 Medisensors had a promising mobile technology, well-heeled backers, and an important goal: a painless way to measure blood sugar.

Read the tale of how it fell apart, and the rest of our report on medical technology, at **technologyreview.com/business.**

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Reviews

In Praise of Efficient Price Gouging

Uber's most important innovation is the way it prices its services. But that innovation has not been unreservedly welcomed by customers. They're wrong.

By James Surowiecki

In the four years since the car service Uber launched, it has been beset by criticism from myriad groups, including city officials annoyed by its sometimes cavalier attitude toward regulation and taxi companies annoyed by increased competition. Some of the harshest criticism, though, has come from an unlikely place: Uber's own customers. Thanks to its reliance on what it calls "surge pricing"— meaning that during times of high demand, Uber raises its prices, often sharply—the company has been accused of profiteering and exploiting its customers. When Uber jacked up prices during a snowstorm in New York last December, for instance, there was an eruption of complaints, the general mood being summed up by a tweet calling Uber "price-gouging assholes."

What's striking about the Uber backlash is that the company is hardly the first to use dynamic pricing. There have always been crude forms of price differentiation—or, as it is known in economics, price discrimination. If you go to a movie matinee, you pay less than if you go at night, and if you're willing to wait to buy a new dress (and run the risk that it might sell out), you can often get it at a marked-down price. But dynamic pricing in a more rigorous sense was pioneered in the 1980s by Robert Crandall, CEO of American Airlines, as a way to fight off competition from discount airlines like People Express. American began by slashing prices for tickets bought well in advance, while keeping prices for tickets bought closer to takeoff (when ticket inventory was lower, and demand was less price-sensitive) as high as possible. In the decades since, this kind of yield management has become integral to the business models of airlines, hotels, and rental-car companies, and greater computing power and more sophisticated data analysis has turned pricing in these industries into an incredibly complex process. (Dynamic pricing has also allowed sites like Priceline and Hotwire to flourish, since when hotels are stuck with extra rooms, they're often willing to drop prices rather than let a room sit empty.) More recently, as technology has made it easier to segment the market and change prices on the fly, dynamic pricing has become common in other industries, too. Many professional sports teams now use it to set ticket prices—games against high-profile teams cost more than games against cellar dwellers—while concert ticket prices wax and wane with demand.

If dynamic pricing is hardly unusual, why has Uber taken so much flak? Some of it is a matter of history: early on, Uber's pricing was not especially transparent, so customers occasionally found themselves stuck with fares that were much higher than they expected. The fact that some of the most high-profile examples of surge pricing have been the result of big storms also matters, since it taps into people's visceral dislike of price gouging. A 1986 study by Daniel Kahneman, Jack Knetsch, and Richard Thaler found that most people thought "raising prices in response to a shortage is unfair even when close substitutes are readily available"—a situation that almost perfectly describes Uber. Then, too, the price increases during surges are often magnitudes greater than customers are used to; during that New York snowstorm, Uber charged up to nearly eight times as much as it usually did. Thaler has suggested that people find price increases above three times normal psychologically intolerable.

Uber's dynamic pricing model

It's also important that Uber's prices only rise above the base rate and never fall below it, since customers seem to accept dynamic pricing more easily when it's characterized as a discount. At the movies, for instance, prime-time tickets aren't presented as a few dollars more than the normal price—rather, matinees are presented as a few dollars less. When American introduced dynamic pricing, it framed the 21-day advance-purchase requirement as a chance to buy "super-saver" fares. And happy hours at bars are, similarly, framed as a markdown from the regular price. These framing devices

don't change the underlying economics or price structure, but they can have a big impact on customer reaction. In 1999, for instance, Douglas Ivester, then the CEO of Coca-Cola, suggested that smart vending machines would allow Cokes to be more expensive on hot days, when demand was presumably higher. There was an immediate, intense backlash, and the company quickly backed down, saying Ivester's comments were purely hypothetical. Had Ivester instead suggested that Coca-Cola could use dynamic pricing to charge less on cold days (even if it had raised the base price of a can), response would probably have been very different. Uber's competitor Lyft seems to have recognized the power of framing: it recently introduced what it calls happy-hour pricing, offering discounts during slow business hours.

Finally, Uber also faces a challenge simply because of the industry it's in: a business in which fares have historically been regulated (for cabs) and fixed (if you take a car service to the airport in New York, for instance, you typically pay the same price whether you leave at 6 A.M. or 5 P.M.). Uber's pricing scheme is more complicated and harder to grasp intuitively, so that even though Uber is transparent about surge pricing, some people inevitably find it vexing. Uber's also combating the sense that transportation is, in some sense, a public utility, and that it's offensive to charge people so much more than they're used to paying. This is a mysterious complaint, since there are many alternatives to using Uber. But it's a surprisingly common one.

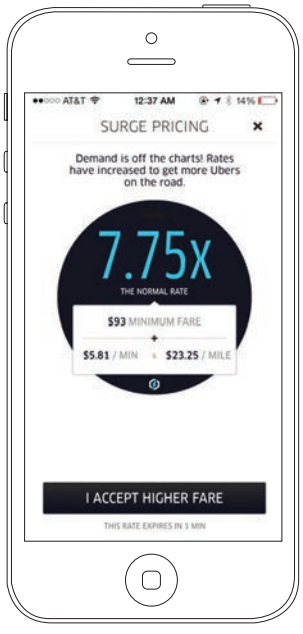
It's easy to see, then, why Uber has become a flash point for criticism. But there is a deep irony here: the company arguably offers the most economically sensible, and useful, example of dynamic pricing in today's economy.

The reality is that the times when people most want a ride are also the times when it's most annoying and, often, most risky to drive: rush hour, New Year's Eve, 2 A.M. on a Saturday night, snowstorms.

In most cases, after all, dynamic pricing is a way for companies to maximize profits by exploiting demand—charging higher prices to people who can and will pay more. As MIT professor Yossi Sheffi has put it, it's the "science of squeezing every possible dollar from customers."

That's because most industries that use dynamic pricing have a limited inventory (an airline flight has a set number of seats, a hotel a set number of rooms) and are trying to make as much money from selling that inventory as possible. Uber's case is different. While the company also wants to make as much money as possible, it uses surge pricing not only to exploit demand but to increase supply.

When there are more would-be Uber passengers than available Uber cars, the company's algorithm sets a price that balances supply and demand. Uber's algorithm (which it has been refining since 2011) is the company's greatest asset and most significant innovation, allowing it to find the price that will attract drivers—whom, as independent contractors, it can't order onto the road—without alienating customers. The strategy works. In a recent blog post, the venture capitalist Bill Gurley, who's an Uber board member, said that when Uber first tested dynamic pricing in Boston in 2012, it was able to "increase on-the-road supply of drivers by 70 to 80 percent."



The Uber app tells users how much the rate has increased during times of high demand.

Plenty of us have an intuition that cab drivers would want to be on the road when there's money to be made. But this isn't the case: a number of studies have shown that there's considerable variety in how they decide when to drive. Also, the reality is that the times when people most want a ride are also the times when it's most annoying and, often, most risky to drive. Rush hour, New Year's Eve, 2 A.M. on a Saturday night, snowstorms: generally speaking, these are exactly the times when a driver doesn't want to be on the road. But if driving at those times pays considerably better, then they are more likely to be willing.

What this means is that in the case of Uber, surge pricing doesn't just make rides more expensive (as is the case with airline tickets or hotel rooms at times of high demand). It also expands the number of people who are actually able to get a ride. Customers pay more, but they also get a ride that they otherwise would not have gotten. This is exactly how a market is supposed to work: higher demand induces more supply.

Of course, Uber has been making this argument for a while now, and it hasn't stopped people from complaining. (Though it hasn't stopped people from using the service, either:

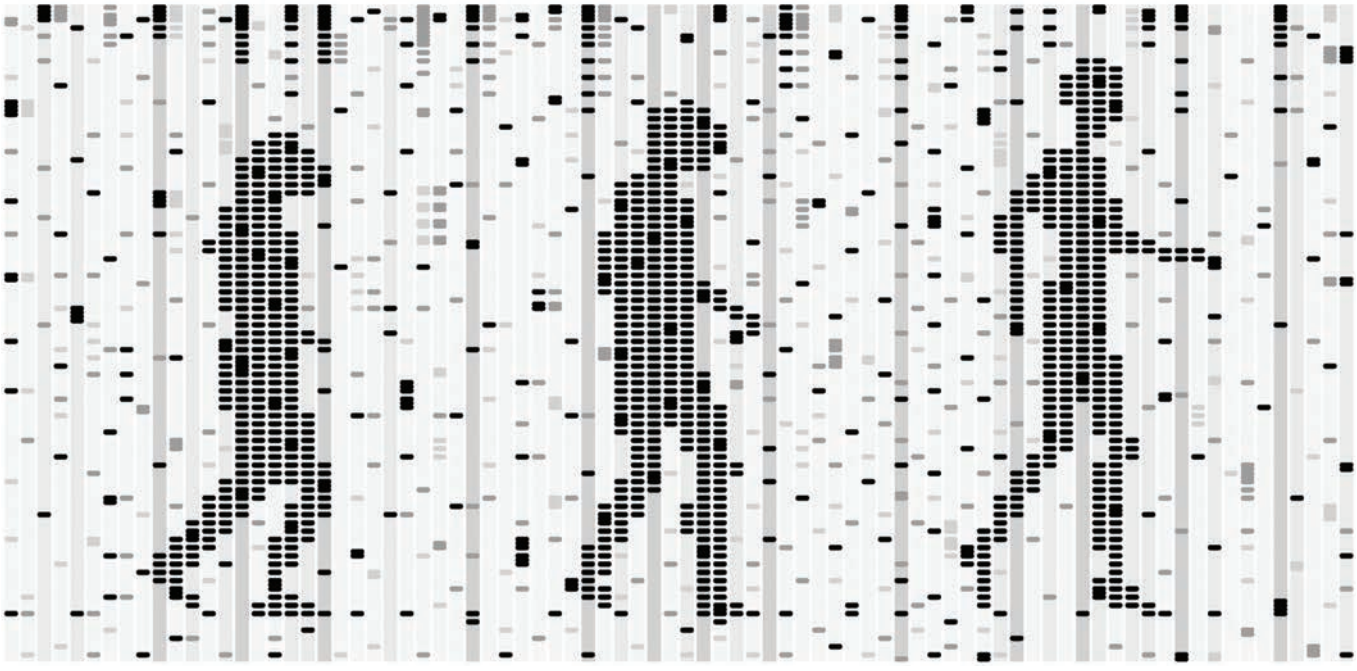
Uber is now valued at more than $17 billion.) So pundits have proffered a number of suggestions for solving the public relations problem.

The company itself should take no money during surge periods (it now takes 20 percent of every fare), so all the money goes to the drivers. Or it should cap prices to consumers but pay the higher price to drivers, essentially subsidizing people's rides in surge periods. Or when prices rise really sharply, Uber should donate its take to charity.

These are all interesting ideas. But it'd be a mistake for Uber to let public relations trump economics when it comes to dynamic pricing. It makes sense that the company recently reached an agreement with New York's attorney general that caps surge pricing during times of "emergency," since these emergencies are rare, and the negative fallout from them can be immense. But tinkering with the basic idea of surge pricing will only reinforce the status quo and bolster people's implicit assumption that prices should be set, in some sense, independently of supply and demand. The basic reality of Uber's business model is that when people want a ride the most, it's likely to be the most expensive. This will always be irritating, just as exorbitant prices for last-minute airline tickets are irritating. But over time, surge pricing will also become more familiar and less surprising.

Utilities are now starting to use dynamic pricing for electric power, which can help prevent blackouts at times of high demand and promote energy conservation more generally. A new startup called Boomerang Commerce, which is led by former Amazon engineers, has been helping online retailers set prices dynamically. Dynamic pricing is the future, even if the road to get there will be bumpy.

James Surowiecki writes "The Financial Page" for the New Yorker.



The History Inside Us

Improvements in DNA analysis are helping us rewrite the past and better grasp what it means to be human.

By Christine Kenneally

EVERY DAY OUR DNA BREAKS A LITTLE. Special enzymes keep our genome intact while we're alive, but after death, once the oxygen runs out, there is no more repair. Chemical damage accumulates, and decomposition brings its own kind of collapse: membranes dissolve, enzymes leak, and bacteria multiply. How long until DNA disappears altogether? Since the delicate molecule was discovered, most scientists had assumed that the DNA of the dead was rapidly and irretrievably lost. When Svante Pääbo, now the director of the Max Planck Institute for Evolutionary Anthropology in Germany, first considered the question more than three decades ago, he dared to wonder if it might last beyond a few days or weeks. But Pääbo and other scientists have now shown that if only a few of the trillions of cells in a body escape destruction, a genome may survive for tens of thousands of years.

Neanderthal Man: In Search of Lost Genomes
by Svante Pääbo
Basic Books, 2014

In his first book, *Neanderthal Man: In Search of Lost Genomes*, Pääbo logs the genesis of one of the most groundbreaking scientific projects in the history of the human race: sequencing the genome of a Neanderthal, a human-like creature who lived until about 40,000 years ago. Pääbo's tale is part hero's journey and part guidebook to shattering scientific paradigms. He began dreaming about the ancients on a childhood trip to Egypt from his native Sweden. When he grew up, he attended medical school and studied molecular biology, but the romance of the past never faded. As a young researcher, he tried to mummify a calf liver in a lab oven and then extract DNA from it. Most of Pääbo's advisors saw ancient DNA as a "quaint hobby," but he persisted through years of disappointing results, patiently awaiting technological innovation that would make the work fruitful. All the while, Pääbo became adept at recruiting researchers, luring funding, generating publicity, and finding ancient bones.

Eventually, his determination paid off: in 1996, he led the effort to sequence part of the Neanderthal mitochondrial

MELVIN GALAPON

genome. (Mitochondria, which serve as cells' energy packs, appear to be remnants of an ancient single-celled organism, and they have their own DNA, which children inherit from their mothers. This DNA is simpler to read than the full human genome.) Finally, in 2010, Pääbo and his colleagues published the full Neanderthal genome.

That may have been one of the greatest feats of modern biology, yet it is also part of a much bigger story about the extraordinary utility of DNA. For a long time, we have seen the genome as a tool for predicting the future. Do we have the mutation for Huntington's? Are we predisposed to diabetes? But it may have even more to tell us about the past: about distant events and about the network of lives, loves, and decisions that connects them.

Empires

Long before research on ancient DNA took off, Luigi Cavalli-Sforza made the first attempt to rebuild the history of the world by comparing the distribution of traits in different living populations. He started with blood types; much later, his popular 2001 book *Genes, Peoples, and Languages* explored demographic history via languages and genes. Big historical arcs can also be inferred from the DNA of living people, such as the fact that all non-Africans descend from a small band of humans that left Africa 60,000 years ago. The current distribution across Eurasia of a certain Y chromosome—which fathers pass to their sons—rather neatly traces the outline of the Mongolian Empire, leading researchers to propose that it comes from Genghis Khan, who pillaged and raped his way across the continent in the 13th century.

But in the last few years, geneticists have found ways to explore not just big events but also the dynamics of populations through time. A 2014 study used the DNA of ancient farmers and hunter-gatherers from Europe to investigate an old question: Did farming sweep across Europe and become adopted by the resident hunter-gatherers, or did farmers sweep across the continent and replace the hunter-gatherers? The researchers sampled ancient individuals who were identified as either farmers or hunters, depending on how they were buried and what goods were buried with them. A significant difference between the DNA of the two groups was found, suggesting that even though there may have been some flow of hunter-gatherer DNA into the farmers' gene pool, for the most part the farmers replaced the hunter-gatherers.

In a very short amount of time, the genomes of ancient people have facilitated a new kind of population genetics. It reveals phenomena that we have no other way of knowing about.

Looking at more recent history, Peter Ralph and Graham Coop compared small segments of the genome across Europe and found that any two modern Europeans who lived in neighboring populations, such as Belgium and Germany, shared between two and 12 ancestors over the previous 1,500 years. They identified tantalizing variations as well. Most of the common ancestors of Italians seem to have lived around 2,500 years ago, dating to the time of the Roman Republic, which preceded the Roman Empire. Though modern Italians share ancestors within the last 2,500 years, they share far fewer of them than other Europeans share with their own countrymen. In fact, Italians from different regions of Italy today have about the same number of ancestors in common with one another as they have with people from other countries. The genome reflects the fact that until the 19th century Italy was a group of small states, not the larger country we know today.

Significant events in British history suggest that the genetics of Wales and some remote parts of Scotland should be different from genetics in the rest of Britain, and indeed, a standard population analysis on British people separates these groups out. But this year scientists led by Peter Donnelly at Oxford uncovered a more fine-grained relationship between genetics and history. By tracking subtle patterns across the genomes of modern Britons whose ancestors lived in particular rural areas, they found at least 17 distinct clusters that probably reflect different groups in the historic population of Britain. This work could help explain what happened during the Dark Ages, when no written records were made—for example, how much ancient British DNA was swamped by the invading Saxons of the fifth century.

The distribution of certain genes in modern populations tells us about cultural events and choices, too: after some groups decided to drink the milk of other mammals, they evolved the ability to tolerate lactose. The descendants of groups that didn't make this choice don't tolerate lactose well even today.

Mysteries

Analyzing the DNA of the living is much easier than analyzing ancient DNA, which is always vulnerable to contamination. The first analyses of Neanderthal mitochondrial DNA were performed in an isolated lab that was irradiated with UV light each night to destroy DNA carried in on dust. Researchers wore face shields, sterile gloves, and other gear, and if they entered another lab, Pääbo would not allow them back that day. Still, controlling contamination only took Pääbo's team to the starting line. The real revolution in analysis of ancient DNA came in the late 1990s,

with second-generation DNA sequencing techniques. Pääbo replaced Sanger sequencing, invented in the 1970s, with a technique called pyrosequencing, which meant that instead of sequencing 96 fragments of ancient DNA at a time, he could sequence hundreds of thousands.

Such breakthroughs made it possible to answer one of the longest-running questions about Neanderthals: did they mate with humans? There was scant evidence that they had, and Pääbo himself believed such a union was unlikely because he had found no trace of Neanderthal genetics in human mitochondrial DNA. He suspected that humans and Neanderthals were biologically incompatible. But now that the full Neanderthal genome has been sequenced, we can see that 1 to 3 percent of the genome of non-Africans living today contains variations, known as alleles, that apparently originated with Neanderthals. That indicates that humans and Neanderthals mated and had children, and that those children's children eventually led to many of us. The fact that sub-Saharan Africans do not carry the same Neanderthal DNA suggests that Neanderthal-human hybrids were born just as humans were expanding out of Africa 60,000 years ago and before they colonized the rest of the world. In addition, the way Neanderthal alleles are distributed in the human genome tells us about the forces that shaped lives long ago, perhaps helping the earliest non-Africans adapt to colder, darker regions. Some parts of the genome with a high frequency of Neanderthal variants affect hair and skin color, and the variants probably made the first Eurasians lighter-skinned than their African ancestors.

Ancient DNA will almost certainly complicate other hypotheses, like the African-origin story, with its single migratory human band. Ancient DNA also reveals phenomena that we have no other way of knowing about. When Pääbo and colleagues extracted DNA from a few tiny bones and a couple of teeth found in a cave in the Altai Mountains in Siberia, they discovered an entirely new sister group, the Denisovans. Indigenous Australians, Melanesians, and some groups in Asia may have up to 5 percent Denisovan DNA, in addition to their Neanderthal DNA.

In a very short amount of time, a number of ancients have been sequenced by teams all over the world, and the growing library of their genomes has facilitated a new kind of population genetics. What is it that DNA *won't* be able to tell us about the past? It may all come down to what happened in the first moments or days after someone's death. If, for some reason, cells dry out quickly—if you die in a desert or a dry cave, if you are frozen or mummified—post-mortem damage to DNA can be halted, but it may never be possible to sequence DNA from remains found in wet, tropical climates. Still, even working with only the scattered remains that we have found so far, we keep gaining insights into ancient history. One of the remaining mysteries, Pääbo observes, is why modern humans, unlike their archaic cousins, spread all over the globe and dramatically reshaped the environment. What made us different? The answer, he believes, lies waiting in the ancient genomes we have already sequenced.

There is some irony in the fact that Pääbo's answer will have to wait until we get more skillful at reading our own genome. We are at the very beginning stages of understanding how the human genome works, and it is only once we know ourselves better that we will be able to see what we had in common with Neanderthals and what is truly different.

Christine Kenneally is the author of The Invisible History of the Human Race, *to be published in October.*

IAN LISHMAN/JUICE IMAGES/CORBIS

A human operator controls a robot in a British facility that makes metal pedestrian barriers.

Love of Labor

Automation makes things easier, whether it's on the factory floor or online. Is it also eroding too many of the valuable skills that define us as people?

By Mattathias Schwartz

MESSAGES MOVE AT LIGHT SPEED. MAPS speak directions. Groceries arrive at the door. Floors mop themselves. Automation provides irresistible conveniences.

And yet automation can also be cast as a villain. When machines take over work that once required sweat and skill, humans atrophy into mere button-pushing operators. Laments about automation are as familiar as John Henry, the railroad steel-driver of lore who could not outlast a steam-powered version of himself. The latest is *The Glass Cage* by Nicholas Carr, who worries about the implications as machines and software advance far past the railroad and the assembly line to the cockpit, the courtroom, and even the battlefield. Machines and computers now do much more than rote mechanical work. They monitor complex systems, synthesize data, learn from experience, and make fine-grained, split-second judgments.

The Glass Cage: Automation and Us
By Nicholas Carr
Norton, 2014

Flow: The Psychology of Optimal Experience
By Mihaly Csikszentmihalyi
Harper Perennial, 1990

Life Work
By Donald Hall
Beacon Press, 1993

What will be left for us to do? While economists and policy makers are debating what automation will mean for

employment and inequality (see "How Technology Is Destroying Jobs," July/August 2013), Carr's book does not sort out those implications. It is about what he fears will be diminished—our autonomy, our feelings of accomplishment, our engagement with the world—if we no longer have to carry out as many difficult tasks, whether at home or at work.

The centerpiece of his argument is the Yerkes-Dodson curve, which plots the relationship between human performance and the stimulation our tasks provide. Too much stimulation makes us feel panicked and overloaded, but when we have too little stimulation—when our work is too easy—we become lethargic and withdrawn. Activities that provide moderate stimulation yield the highest level of performance and, as Carr argues, turn us into better people in the process.

Carr, a former executive editor of *Harvard Business Review* and an occasional contributor to this magazine, has written several books that have challenged common beliefs about technology, like the added value of IT for businesses and the cognitive benefits of Google. In *The Glass Cage* he is channeling the anxieties of the contemporary workplace. Even talented white-collar workers feel as though they are half a generation from being rendered obsolete by an algorithm. But Carr is not analyzing the economic consequences of automation for the workforce at large. The book begins with a warning to airline pilots from the U.S. Federal Aviation Administration not to rely too much on autopilot. He narrates two crashes, tracing their cause to pilot inattention caused by the autopilot's lulling effects. This reads like the opening of a utilitarian argument against automation: we ought to let pilots do their jobs because computers lack the judgment necessary to preserve human life during moments of crisis. Later, we learn that the safety records of Airbus planes and the more pilot-oriented planes built by Boeing are more or less identical. Carr's core complaint is mainly about the texture of living in an automated world—how it affects us at a personal level.

At times, this seems to be coming from a position of nostalgia, a longing for a past that is perhaps more desirable in retrospect. Take GPS. To Carr, GPS systems are inferior to paper maps because they make navigation *too* easy—they weaken our own navigational skills. GPS is "not designed to deepen our involvement with our surroundings," he writes. The problem is, neither are maps. Like GPS, they are tools intended to deliver their user to a desired destination with the least possible hassle. It is true that paper maps require a different set of skills, and anyone who finds this experience of stopping and unfolding and getting lost more enlivening or less emasculating than the new incarnation of wayfinding can choose to turn GPS off, or use the two technologies in tandem.

In the zone

The classic account of life at the top of the Yerkes-Dodson curve is Mihaly Csikszentmihalyi's *Flow: The Psychology of Optimal Experience*, published in 1990. Flow is a concept of almost poetic vagueness, hard to measure and even harder to define. Csikszentmihalyi found it in all kinds of people: athletes, artists, musicians, and craftsmen. What makes "flow" more than a flight of fancy is that almost anyone will recognize the feeling of "losing oneself" in a challenging task or being "in the zone." As a concept, flow erases the boundary that economists draw between "work" and leisure or recreation, and Carr wants automation to be designed to produce it. Ideally it would have a Goldilocks just-right quality, relieving drudgery but stopping short of doing everything.

Like Carr, Csikszentmihalyi valorized physical work—which might be easier to do if you don't rely on it for subsistence or a paycheck—and fretted that automation would deny laborers the chance to achieve flow. "The typical laborer now sits in front of a bank of dials, supervising a computer screen in a pleasant control room, while a band of savvy robots down the line do whatever 'real' work needs to be done," he wrote. Most people, he observed, now did "jobs that would surely appear like pampered leisure to the farmers and factory workers of only a few generations ago."

But surely the opportunities for flow or fulfillment depend more on your approach to your work than on the selection of the right technologies. The poet Donald Hall wrote in *Life Work*, his 1993 memoir, that even though his deskbound life was easier than those of his grandparents, New Hampshire farmers who split wood, baled hay, milked cattle, and canned vegetables, both his work and theirs gave rise to daily routines, which lead to "absorbedness," a flow-like state in which the hardness of hard work is dissolved by skill and habit. The conversation around what makes for "hard work" may tend to refer to physical labor because it is an easier process to narrate and observe. Hall suggests that the rhythms of work performed at a desk might not be so different, and that it is intention and discipline—not technology or other material conditions—that define the work we do. (Then again, he chose to write in longhand rather than use a typewriter or a computer. And he was writing about writing before the distractions of e-mail and Twitter.)

***The Glass Cage* channels the anxieties of the contemporary workplace. Even talented white-collar workers feel as though they are half a generation from being rendered obsolete.**

Carr spends most of *The Glass Cage* treating automation as though it were a problem of unenlightened personal choices—suggesting that we should often opt out of technologies like GPS in favor of manual alternatives. Yet the decision to adopt many other innovations is not always so voluntary. There is often something seductive and even coercive about them. Consider a technology that Carr himself discusses: Facebook, which seeks to automate the management of human relationships. Once the majority has accepted the site's addictive design and slight utility, it gets harder for any one individual to opt out. (Though Facebook may not look like an example of automation, it is indeed work in disguise. The workers—or "users"—are not paid a wage and the product, personal data, is not sold in a visible or public market, but it does have a residual echo of the machine room. Personal expression and relationships constitute the raw material; the continuously updated feed is the production line.)

Carr flirts with real anger in *The Glass Cage*, but he doesn't go far enough in exploring more constructive pushback to automation. The resistance he endorses is the docile, individualized resistance of the consumer—a photographer who shoots on film, an architect who brainstorms on paper. These are small, personal choices with few broader consequences. The frustrations that Carr diagnoses—the longing for an older world, or a different world, or technologies that embody more humanistic and less exploitative intentions—are widespread. For these alternatives to appear feasible, someone must do the hard work of imagining what they would look like.

Mattathias Schwartz is a freelance writer and regular contributor to the New Yorker. *His last piece for* MIT Technology Review *was "Fire in the Library" (January/February 2012).*

Demo


Eugene Chow

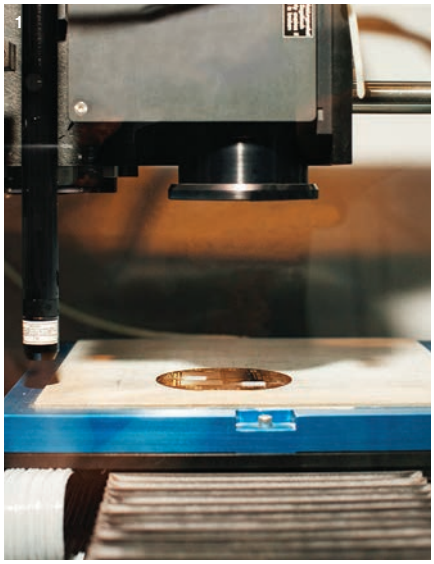
Micro Chiplets

PARC's technique of mincing chips into printer ink could revolutionize the way electronics are made.

By David Talbot
Photographs by Leah Fasten

IN THE SAME RESEARCH LAB WHERE THE ETHERNET, LASER printer, and graphical user interface were born, engineers are forging an entirely new way to assemble electronic devices—a technique that could be faster, cheaper, and more versatile.

Typically, chips are made in bulk on semiconductor wafers and then cut into individual units and placed on motherboards inside computers and other devices. But researchers at PARC, in Palo Alto, California, envision doing something different with the wafers: chopping them up into hairs-width "chiplets," mixing them into an ink, and guiding the tiny pieces electrostatically to just the right spot and orientation on a substrate, from which a roller could pick them up and print them.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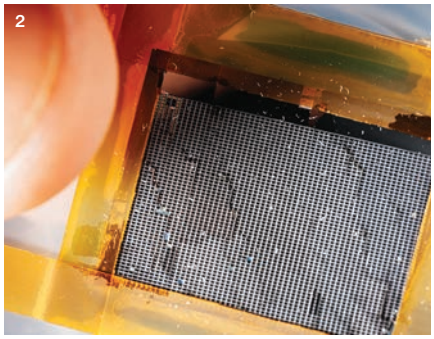
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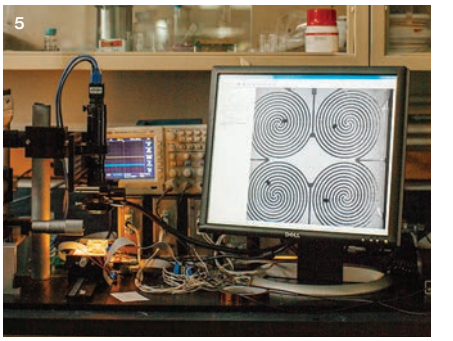
1 A laser etching tool minces a silicon wafer into tiny "chiplets."

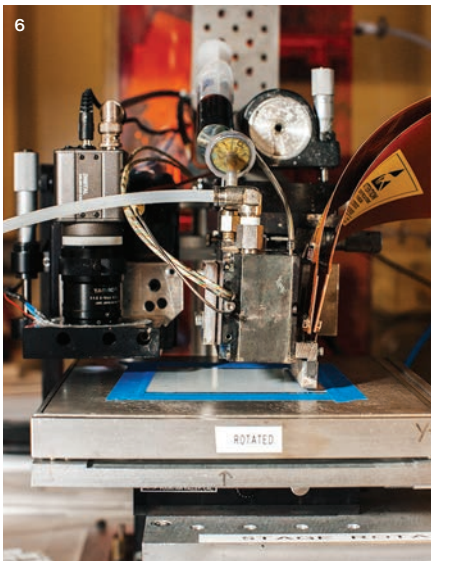
2 The thousands of chiplets have positive and negative charges, applied to the wafer by way of thin films.

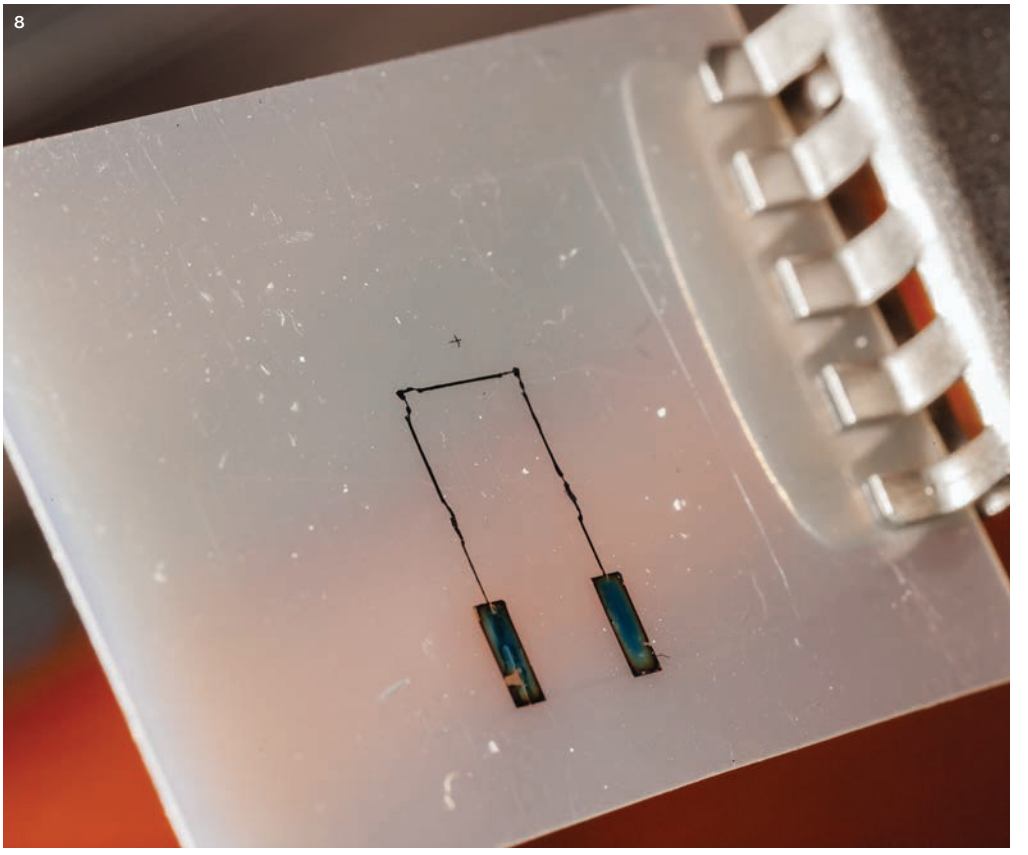
3 The chiplets, each 200 micrometers by 300 micrometers, are placed in a fluid.

4/5 Four chiplets are guided into place on a glass substrate using complex electrical fields generated by wires in a spiral pattern.

6 After a roller deposits the four chiplets on a plastic substrate, a printer wires them together.







7/8 Four chiplets, barely visible at corners and middle of lines at right, are now connected by printed wires in a proof of manufacturing concept. Two electrodes are visible at bottom.

Although now at a very early stage, the technology could lead to novel kinds of computing devices, such as high-resolution imaging arrays made from tiny ultrasensitive detectors assembled by the million. Because printers can deposit materials on different substrates, this technology could be used to make high-performance flexible electronic devices, tiny sensors festooned with dense arrays of diverse sensors, or 3-D objects with computing functions woven in, says Janos Veres, who manages PARC's printed-electronics team. And the approach could make it easier for more people and small companies to design and manufacture custom computing devices.

PARC's vision for the technology starts with wafers made by conventional methods and designed to hold thousands of tiny functioning devices. These could include LEDs or lasers, processors and memory, or sensors based on microelectromechanical devices, or MEMS. They'd all become feedstocks for a palette of chip-infused inks. Existing electronics-printing systems generally use lower-performance materials, but "potentially, we can use the absolutely highest-performance chips on the market," says Eugene Chow, an electrical engineer who leads the project.

The technology marshals chiplets into place using software-controlled electrical fields generated by arrays of wires beneath an assembly substrate. Like balls rolling into divots, the chiplets go to locations defined by the electrical fields. "The fields are changing in time and space in all kinds of fancy patterns that can be controlled to allow high-throughput assembly," Chow says.

For now, placement is aided by simple positive and negative charges added to chiplets before the wafers are minced. For a printing system to handle different kinds of chiplets, PARC envisions differentiating them with unique charge-based bar codes or creating multiple printing steps, with one type of chiplet set down at each step. "Years from now, if this works, it's a new platform where we put millions and billions of things together," Chow says.

The first hurdle is figuring out how to precisely assemble chiplets; so far, PARC has managed to place four at a time and then wire them together in a second step. Still, that achievement is a start toward "accelerating the evolution of microelectronics," Veres says. "We can iterate new circuits every minute, opening up thousands of uses."

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15 Years Ago

The Future Is Now

Fifteen years ago we launched the TR100 to celebrate the magazine's centennial. The feature has since evolved into our annual 35 Innovators Under 35 list. Here are some standouts from year one.

MARC ANDREESSEN
"He became one of the first overnight Internet multimillionaires when Netscape made its Wall Street debut ... Andreessen exudes gawky charm, and displays a polymath's knowledge of the most exotic subjects."

KRISTI ANSETH
"Anseth develops new types of photopolymers, plastics that go from soft to hard when struck by ultraviolet light. Anseth has invented novel photopolymers that actually wear away over time—a feature that promises much for orthopedic repairs."

BONNIE BERGER
"Berger is leading a group of computational biologists to develop software that ... predict[s] protein folding based on the sequence of amino acids. Such insights could eventually lead to new drugs to combat viral disease such as AIDS."

SKY DAYTON
"He founded Earthlink Network—now one of the nation's top five Internet service providers. Attribute that success to ... innovations such as the $19.95 monthly flat rate when most ISPs were still clinging to the notion of hourly fees."

HELEN GREINER
"These days, robots are typically used in limited, specialized roles. But if Helen Greiner and Colin Angle [her cofounder at the company that would become iRobot] have anything to say about that, robots may soon be a more versatile and ubiquitous part of our lives."

JONATHAN IVE
"While Ive's work helped Apple distance itself from the pack, that wasn't the primary purpose for his group's innovative design, he says. 'Our goal wasn't just to differentiate our product, but to create products that people would love in the future.'"

NATALIE JEREMIJENKO
"Jeremijenko's aim is to pierce the 'hallucination' that cyberspace is somehow clean. In reality the digital domain is a world of hard truths. Silicon Valley is home to a large concentration of toxic waste sites and one of the nation's largest gaps between rich and poor."

JOHN ROGERS
"Rogers has developed a series of novel fabrication techniques to make transistors from organic polymers, and integrated circuits on curved surfaces. The new transistors could be utilized in a flexible computer display consisting of a thin sheet of plastic."

THAD STARNER
"What happens when computers become part of us, attached to our bodies like clothes or eyeglasses? That's a question Thad Starner has been asking—in practice—since 1993, when he developed his first wearable computer system."

LINUS TORVALDS
"If operating-system software has a revolutionary hero, it is Linus Torvalds. The movement is 'open-source' software—in which a system's source code is freely shared and collectively improved. This model has moved into the computing mainstream largely due to [Torvalds]."

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